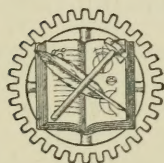# SOIL MINERALOGY

*A Discussion of Mineralogy in its Application
to Soil Studies*

BY

FREDERICK A. BURT

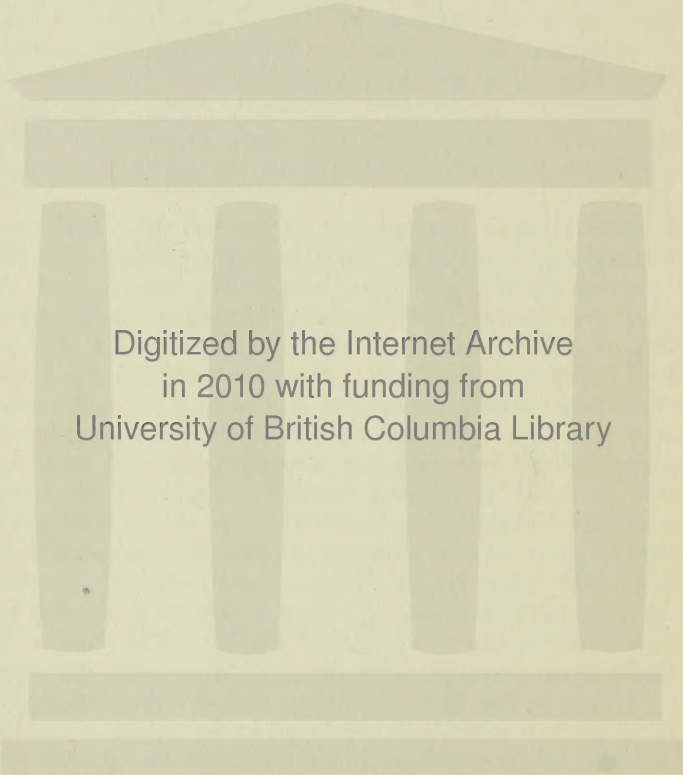*Associate Professor of Geology, A. & M. College of Texas*

PREFACE

THE accompanying text on Soil Mineralogy has developed as a result of thirteen years of experience in the teaching of Soil Geology and Mineralogy in the state agricultural and engineering colleges of Michigan, Mississippi, and Texas. In the author's experience he has found no text or reference book on Mineralogy which has treated the subject from the viewpoint of the student or professional worker in soils. The belief that the need for such a book exists in many of our agricultural schools, colleges, and experiment stations has led to the writing of this text.

The dissociation of the minerals in the soil from their normal petrographic associations, their intimate contact with air, water, organic matter, and other weathering agents, and the eroded and greatly weathered condition of many of them render the study of soil minerals peculiarly difficult and a distinct branch of mineralogical science. For these reasons there will be noted several striking departures of this book from the usual book on mineralogy. The most notable of these departures are: the omission of all minerals not directly concerned with soil formation or used as mineral fertilizer, the relatively large amount of chemical data, the relatively large space given to the discussion of physical and chemical changes due to weathering, the use of such terms as "pyroxene" and "olivine" in their broad sense to cover a group of closely allied varieties, and the unfortunate double use of the word "alkali". The word when used in its true chemical sense is written without quotation marks. Where it has been necessary to use the word in the sense in which it is commonly employed by agronomists this has been indicated by its enclosure in quotation marks. As the curricula of our agricultural colleges does not allow the time necessary for the study of the elementary principles of crystallography the crystal properties and characteristics of the minerals have been omitted.

F. A. B.

College Station, Texas,
  Feb. 15, 1927.

iii

Digitized by the Internet Archive
in 2010 with funding from
University of British Columbia Library

CONTENTS

PART I

GENERAL PRINCIPLES

PART II

DETERMINATIVE MINERALOGY

PART III

DESCRIPTIONS OF MINERAL SPECIES

PART IV

SUPPLEMENTARY TABLES

ERRATA

Page 18, line 24, next to the last word, for "fluorine" read "fluorite"

Page 55, line 14, for "$2NaAlSi_2O_8$" read "$2NaAlSi_3O_8$".

Page 65, line 31, for "calicum" read "calcium".

LIST OF ILLUSTRATIONS

SOIL MINERALOGY

PART I

GENERAL PRINCIPLES

CHAPTER I

PHYSICAL PROPERTIES OF MINERALS

Color

The color of a mineral, although the first physical property usually noticed by the observer, is one of the least important and most unreliable of mineral properties for identification purposes. In metallic minerals the color is a fairly constant and reliable identifying property but among the non-metallic minerals, which include the great majority of mineral fragments in the soil, the color may vary very greatly in a single species.

The variation of color in a species may be due either to the presence of chemically dissolved material, partial substitution of the bases of the material, partial decomposition, or the presence of mechanically mixed foreign material.

Chemically dissolved material, either organic or inorganic, is of frequent occurrence. The presence of such material to the amount of only a few one-hundredths of one per cent may be sufficient definitely to alter the color of the pure mineral compound. The colors of quartz and calcite are notably susceptible to this type of alteration. Chemically dissolved material may be present in minerals crystallized from magmas, precipitated from solution, or formed by metamorphic changes in preexisting minerals.

Partial substitution of bases in a mineral is often accomplished through the agency of heat or by chemical solutions. Variation in color from this cause may be illustrated by the changes seen in the color of hornblende as the ratio between the bases varies.

Partial decomposition of a mineral by weathering may alter the color either through the oxidation or hydration of the iron, as illustrated by the decomposition of hematite to limonite, or by leaching out of some constituent of the mineral as shown by the lightening of the color of biotite by the removal of iron.

Mechanically mixed foreign matter may be present in the form of inclusions as magnetite inclusions in mica which cause black spots so close together as to give either a mottled effect or a general dark appearance. Another type of discoloration from foreign matter is observed in the pink so frequent in orthoclase and produced by the presence of minute particles of ferric oxide.

Tarnish occurs on many metallic minerals and is often confused by the observer with the true mineral color. As tarnish does not extend deeply into the mineral the true color may be observed by breaking the specimen and noticing the color of the freshly exposed surface. Tarnish is produced by chemical change of the acid radical and is most common in sulphide minerals or minerals which exhibit a ready susceptibility to oxidation. Pyrite frequently shows a greenish tarnish which marks the first stage of the oxidation of the iron sulphide to sulphate.

Iridescence and color play are phenomena observed in many minerals containing minute uneven fracture lines, as opal. Color play may be due to minute inclusions of foreign matter as in the case of labradorite.

Streak

The streak is the color of the mineral powder. It is most commonly obtained in laboratory practice by rubbing an edge of the mineral across a white, unglazed porcelain plate called a streak plate. The word streak is derived from this process of obtaining the color of the powder by observing the color of the streak left on the plate. The streak of very hard minerals cannot be obtained by this method and streaks of some metallic

minerals may be incorrectly recorded due to the mingling with the powder of particles of surface tarnish or oxidation. The streaks of the iron minerals, except the silicates, and the micas may be conveniently obtained by careful fine grinding of a fresh piece in a small agate mortar. In general the streaks of metallic minerals are dark while non-metallic minerals have light streaks. Streak is one of the most invariable characteristics of a mineral and hence one of the most valuable in identification.

Color and streak may be the same or different. The only rule that can be laid down on this point is that a white mineral always has a white streak.

Lustre

This term is used to describe the quality of light reflected by a mineral. In observing lustre the beginner is in danger of allowing the color of a mineral to affect his judgment. Distinction between color and lustre should be carefully made. Color depends upon which of the spectrum rays of light are absorbed and which reflected or transmitted. Lustre depends not upon the *color* of the rays which are reflected but upon the *way* in which they are reflected. Chemical composition and physical structure are the two determining factors of lustre.

There are two *types* of lustre, metallic and non-metallic.

Metallic lustre is exhibited by a substance which is opaque even in the thinnest sections. The substance may absorb all the rays of light and thus be both black and metallic as cast iron, or it may reflect certain rays and completely absorb the remaining and thus be colored and metallic as copper. The soil minerals exhibiting metallic lustre are the oxides of iron, titanium and manganese, the hydroxides of iron and manganese, the sulphides of iron, the titanites, and the metaferrites.

Non-metallic lustre is the lustre exhibited by minerals which transmit at least a part of the light which falls upon them. There are eight sub-types of non-metallic lustre found among soil minerals.

Vitreous is the most common sub-type of lustre found among these minerals. It is the lustre possessed by glass and is produced in minerals in which the reflected light comes entirely from the surface.

Pearly and silky lustres are produced by reflection of some of the light from the surface united with some light reflected from the subsurface. Pearly lustre is that illustrated by mother of pearl and is very common, on the surfaces parallel to the cleavage, in minerals of foliated or micaceous structure. The cleavage surfaces of mica illustrate pearly lustre in a most excellent way. At right angles to the cleavage such minerals frequently show a vitreous lustre. Silky lustre is produced by irregular reflection from a substance of fibrous or acicular structure. The sheen is produced by the reflection of white light from the surface together with a considerable amount of more or less colored light from below the surface.

Waxy and greasy lustres are closely related and are common in amorphous minerals, being seldom met with in crystalline structures. They receive their names from the characteristic lustres exhibited by wax and grease.

Oily lustre is so named because of the oily appearance of the mineral surface. It is found on either amorphous or crystalline minerals.

Earthy lustre is a term sometimes employed to describe the dull irregular reflection from a finely granular substance. Strictly speaking it is not the name of a distinct lustre but rather is descriptive of a very dull reflection of submetallic type.

Submetallic is employed to describe the lustre of a non-metallic mineral which exhibits some of the surface characteristics of a metallic mineral. This is often observed in biotite, the reflected light from the surface having some of the characteristics of the light reflected from the surface of a metal, but the translucency of the mineral easily proves it to belong to the non-metallic class.

A mineral may exhibit two kinds of lustre simultaneously. This may be accomplished, as in the case of muscovite which is pearly on the cleavage surfaces and vitreous on the fractured edges, or as in calcite rhombs which partake of some of the characteristics of a vitreous and some of those of a pearly lustre on the same face. A mineral may also exhibit one kind of lustre in one specimen and another kind in another specimen of different form as serpentine which occurs in fibrous masses which are

typically silky, and in amorphous masses which are normally waxy.

Three terms, bright, shiny, and dull are used to indicate the *degree* of lustre. If the lustre is intense and the reflection of light regular enough to produce an imperfect image it is said to be shiny in degree. A less regular reflection of a large amount of the light falling upon the surface gives a bright degree. If a small amount of light is reflected, and that irregularly, the lustre is said to be dull. The degree of lustre is often greatly affected by weathering as shown by mica which loses its brilliancy and becomes dull on long exposure.

Tenacity

Tenacity is the quality of the resistance to a stress applied to a mineral and is dependent on the molecular structure. The minerals of the soil show six distinct types of tenacity which are designated as: brittle, elastic, flexible, friable, sectile, and tough. The degree of cohesion varies greatly, some minerals resisting all but the greatest stresses while others yield to slight stresses.

Brittle. The characteristic of breaking without bending or changing shape appreciably until the limit of the power of holding together is reached. This is the most common type of tenacity.

Elastic. In thin pieces the mineral will bend and spring back to its original position when the stress is removed.

Flexible. A thin piece will bend without breaking but on the removal of the stress will retain its new position.

Friable. Friable minerals yield easily to a blow or steady pressure and crumble into a powdery or finely granular mass.

Sectile. The mineral can be cut without breaking or crumbling.

Tough. The resistance to tearing apart is great.

The tenacity may change as a mineral weathers. For example biotite when fresh is highly elastic, but on weathering gradually loses its elasticity until it becomes very brittle. Limonite and the feldspars, which are normally very brittle, be-

come so friable on long exposure as to crumble under the processes of soil cultivation.

Hardness

The hardness of a mineral is the measure of its resistance to abrasion. It is a property dependent on both the chemical composition and the physical structure. Hardness is a variable, and often a misleading identifying characteristic. The variations in hardness may be due to: (1) variation in composition, (2) the kind and amount of impurity present, (3) variation in structure, (4) the stage of weathering reached, or (5) the face of the mineral upon which the hardness is tested.

Some minerals of highly complex formula, as tourmaline and garnet, vary considerably in composition and their hardness varies as their composition varies. Some minerals with easily replaceable bases, as dolomite in which the calcium and magnesium may each replace a considerable portion of the other, vary as the proportion of the bases varies. The ratio of ferrous to ferric iron in the iron minerals is a factor in determining their hardness.

The presence of impurities within a mineral tends to change the hardness of the mineral in the direction of the hardness of the impurity. Thus impurities within the hardest minerals generally decrease the hardness of the mass while impurities within the softest minerals tend to increase the hardness of the whole.

Hardness varies somewhat with the structure as evidenced by the slight difference in hardness between the foliated and fibrous forms of talc, or between the various forms of calcite.

The effect of weathering is usually to soften the mineral weathered. This is especially noticeable in the silicates. Orthoclase and hornblende, which when fresh are about as hard as good knife steel, become so soft on thorough weathering as to be easily cut.

For the relative statement of the hardness of a mineral a scale has been established and agreed upon. This scale is made by taking as standards ten well-known minerals of little variation. The softest of these minerals is considered as having a hardness of one and the hardest as having a hardness of ten. The length of the steps between successive minerals is by no means uniform,

number 10 being farther from number 9 than 9 is from 1, yet the series is valuable as a scale against which to standardize any material. As generally accepted the scale is as follows:

1. Talc (foliated).
2. Gypsum (foliated).
3. Calcite (rhombic).
4. Fluorite.
5. Apatite.
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Sapphire.
10. Diamond.

The hardness of a mineral is usually determined by rubbing a fresh, flat surface with the edge or corner of one of the minerals of the standard series and then reversing the operation. The harder of the two minerals will distinctly scratch the softer. If a mineral is found to have the same hardness as fluorite it is recorded as 4. If it is harder than fluorite but softer than apatite it is considered as having a hardness of 4.5. Minerals softer than 2.5 are considered as very soft, from 2.5 to 4 as soft, 4 to 6 hard, 6 to 7 very hard, and above 7 as adamantine.

A rough standard for field work may be taken as follows:

Can be scratched by thumb nail—below 2.5.
Cannot be scratched by thumb nail but easily scratched by knife blade—2.5 to 4.
Scratched by knife blade with difficulty—4 to 6.
Not scratched by knife blade but can be scratched by quartz —6 to 7.
Cannot be scratched by quartz—over 7.

A few common errors in the testing of hardness must be guarded against. Friable and granular minerals, as olivine, crumble readily and give the false impression of being soft. Bladed minerals, as hornblende, are often tested with a knife blade in such a manner that the knife enters between the mineral blades separating them rather than abrading the surface of a blade. A streak of powder left on the face of a harder

mineral by drawing a softer one across it is sometimes mistaken for a scratch. A weathered, rather than a fresh surface, is tested. All of these errors are in the direction of making the hardness appear less than it really is. An error is sometimes made in the opposite direction by testing the flat surface of a mineral with a splinter of a hard, very brittle mineral which will break off. It should always be kept in mind that resistance to pressure or a blow is independent of hardness.

Cleavage

Cleavage is the separation along smooth planes which is exhibited by a large number of soil minerals. It is one of the most constant and characteristic properties of minerals and therefore one of the most reliable and important ones in identification work.

The presence of definite cleavage planes within a mineral indicates directions along which cohesion and molecular attraction are weaker than in other directions. Amorphous minerals, being homogeneous throughout, contain no planes of special strength or weakness and therefore show no cleavage. Although cleavage is a property, like tenacity, dependent largely on molecular cohesion the two properties are independent of one another and neither the cleavage nor the tenacity can be foretold from the other.

Cleavage is constant so long as the mineral remains unweathered but frequently soil particles are met with in which weathering has so far proceeded as to destroy the characteristic cleavage. This is particularly true in the case of altered feldspars which soften and crumble without determinable lines of parting.

A mineral may show no cleavage, or a cleavage in one, two, or more directions. This is often expressed by the figures 0, 1, 2, etc. The relationship of these planes of cleavage is definitely expressed by indicating the angle at which the planes meet, thus in orthoclase two cleavage planes meet at right angles (Fig. 1), while in hornblende two planes always meet at an angle of 124° 11'. When a cleavage exists in three directions it may be described by indicating the geometric figure bounded by the cleavage planes, thus are produced cubic cleavage, rhombohedral cleavage, etc.

Cleavage in one direction is manifest by the production of smooth planes. If cleavage is present in two or three directions the broken face of the mineral may exhibit a step-like series of blocks.

The clearness with which the cleavage is observable and the degree of the perfection of parting is indicated by the terms perfect, distinct, and imperfect. Perfect cleavage indicates

Fig. 1
Orthoclase, showing typical appearance of fresh surface, laminated structure, and uneven fracture across cleavage plane.

smooth, lustrous surfaces which may always be obtained unless the mineral is very impure or highly weathered. Distinct indicates a less degree of smoothness of plane. Imperfect indicates a surface somewhat rough or rounded and not highly lustrous.

Fracture

Fracture is separation along indefinite, and generally irregular, lines. Fracture is a less valuable characteristic than cleav-

age on which to identify minerals both because it sometimes
varies within a single mineral species and also because it is not
easily observed in minerals possessing good cleavage. Fracture
is a property of all minerals and its kind is profoundly influ-
enced, and often completely determined, by the internal struc-
ture.

Fig. 2
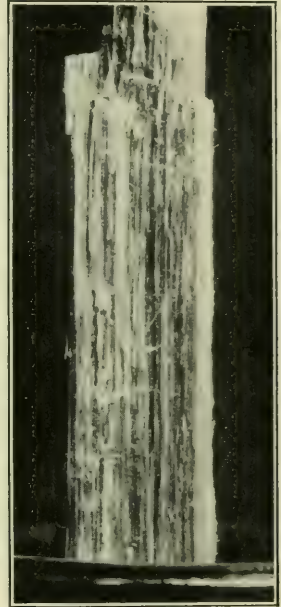Kaolinite, showing the curved edges and
surfaces of conchoidal fracture.

Fig. 3
Serpentine, illustrating
acicular to fibrous struc-
ture and splintery frac-
ture.

The fractures observed in soil minerals may be described as
conchoidal, subconchoidal, splintery, hackly, uneven, and ir-
regular.

Conchoidal, or shell, fracture is one of the most common
(Fig. 2). The lines of breakage are curved, giving convex and
concave surfaces. When the convexities and concavities are but
poorly developed the fracture is said to be subconchoidal.

Splintery. A fracture possessed by many minerals especially those of fibrous or acicular structure and by some of bladed structure (Figs. 3 and 4).

Hackly. With sharp, jagged edges and points as produced on the edges of mica.

Uneven. The surface of the break is rough.

Fig. 4
Actinolite, showing bladed structure and
splintery fracture.

Irregular. No definite shape to the surfaces which are often of great number and varying sizes and meet with sharp irregular edges.

Specific Gravity

Specific gravity is the ratio of the weight of a substance to the weight of an equal volume of distilled water at 4° Centigrade. In practical mineralogical work water of room temperature is used. A few water-soluble minerals must be determined

in some liquid in which they are not soluble and the obtained gravity multiplied by the specific gravity of the liquid used.

The specific gravity of any pure mineral of fixed chemical composition is constant. Considerable variation within a species may be met with, due to the presence of impurities or to substitution among the bases.

The minerals here described range from mirabilite, 1.48 to pyrite, 5.2. The average specific gravity of the twenty-three most abundant soil minerals is 3.34. Omitting the very abundant sulphides, oxides, and hydroxides of iron this average would be 2.84.

In spite of the narrow range of specific gravities and the variations found within a mineral this is a very important and useful property in the determination of species and should always be carefully determined.

Fusibility

The fusibility of a mineral is dependent upon its chemical composition. It is a very definite and dependable property but as it is impossible to test the melting temperature of minerals in ordinary laboratory work the degree of fusibility must be recorded in such general terms as: easily fusible, fuses with difficulty, infusible.

In determining fusibility a very small fragment of the mineral must be used and held in the forceps in such a manner that the blowpipe flame does not hit the forceps and the heat be thus conducted away. Fusion is to be tested with the oxidizing flame and without a flux (Fig. 5).

An easily fusible mineral is one which will melt in splinters as large as a coarse sewing needle. A mineral which fuses with difficulty will round off only on the thinnest edges and points of splinters. An infusible mineral retains its sharpest edges unrounded after treatment for a couple of minutes with the blowpipe flame.

Form

The form of a mineral refers to the external shape or outline of the mineral aggregate and is largely dependent on the

conditions under which the mass originated and the agencies by which it was produced. Form is not, therefore, an inherent property of the mineral except in so far as the outward shape may be determined by the inner structure.

The form of the minerals is not regularly recorded in the description of the species except in a few cases in which it is partly controlled by the internal structure. In these cases it is recorded together with the structure.
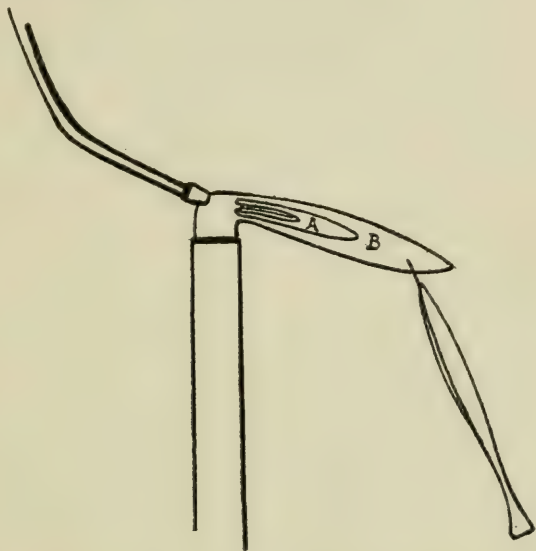

Fig. 5

Bunsen flame and blowpipe, illustrating reducing flame, *A*, and oxidizing flame, *B*, with a splinter of mineral in its tip.

Botryoidal, small, rounded masses resembling bunches of grapes. Mammillary, similar to botryoidal but the rounded masses are larger. Nodular, in regular or irregular lumps of varying size. Oolitic, in small, rounded grains like fish roe. Stalactitic, masses of icicle shape. Crusts or incrustations, surface coatings deposited on material of a different kind. Drusy, large numbers of very small crystals implanted upon a surface. Pseudomorphic, developed in the form or image of some other

mineral as limonite which is frequently found with the outward form of pyrite.

Structure

The structure of a mineral is one of its most outstanding and easily recognized characters. The structure is the product of the chemical composition and the physical conditions under which the mineral was formed. Many minerals, as gypsum, occur in more than one kind of structural condition while other minerals, as biotite, always exhibit the same structure. In some of the minerals which exist with more than one type of structure, as serpentine, which may be granular or fibrous (Fig. 3), the various structures represented are apparently unrelated. In other minerals, as hornblende, which may be fibrous, columnar, or bladed, the different structures manifested are but variations of one fundamental type.

There are two primary classes or groups of structure, the crystalline, and the amorphous. Crystalline minerals are those in which the grouping of molecules is such that the mineral possesses different qualities in one plane or direction than possessed in another. Crystalline minerals may thus show different transmission of light, color, lustre, transmission of electricity, conduction of heat, hardness, cleavage, or lines of structure in one direction than in another. Differences in all these properties in different directions are not essential nor is it essential that the differences be great enough to be readily perceptible, but it is always evident in at least one of the properties in measurable amount. The great majority of minerals are crystalline (Fig. 6, A).

Amorphous minerals are of two kinds: (1) earthy or pulverulent, composed of loosely coherent particles, and (2) glassy, of continuous, homogeneous mass throughout. They are without perceptible definite arrangement of molecules (Fig. 6, B) but appear homogeneous and react equally in all directions to any energy applied to them. Amorphous minerals often appear fibrous, foliated, etc., but these apparent structures are not real but rather are forms assumed because of special conditions involved in the making of the mineral.

Crystalline structures may be collected into three groups: the granular, laminated, and attenuated.

Granular structures are due to the mineral mass consisting of aggregates of small, imperfect crystals which are of nearly equal dimensions in all directions. Compact structure differs from the ordinary granular only in the microscopic or sub-microscopic size of the grains.

The laminated structures (Fig. 1) are produced by organization into crystals with two longer and one shorter dimension, or by the development of good cleavage in one plane. The most common of these structures are the foliated and the micaceous in which the mineral splits into sheets, and the scaly in which the
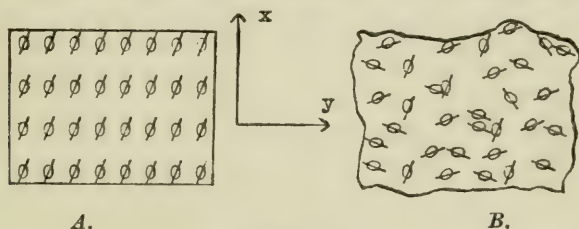

A.   B.

Fig. 6

Diagrammatic representation of the difference in molecular structure of a crystalline mineral, *A*, and an amorphous mineral, *B*. In *A* the molecules are regularly placed in a symmetrical plan whereby the properties in direction *x* differ from those in direction *y*. The properties of the mineral in either direction are the same regardless of the level at which they may be tested. In *B* the molecules are irregularly placed and no definite lines or planes of specific character are distinguishable.

division is into scales. Tabular crystals are proportionally thicker. A striated structure is due to finely drawn, parallel cleavage or twining lines across the mineral face.

Attenuated or prismatic structures may be considered as fibrous, acicular, or columnar according to the coarseness of the individual divisions which may be compared to fibres, needles, or small columns. A bladed structure (Fig. 4) is a columnar structure which approaches the laminated through the broadening of the columns.

CHAPTER II

THE ELEMENTS OF THE SOIL MINERALS

The important soil minerals are composed of but twenty-one elements, of which eight, fluorine, chlorine, zirconium, boron, nitrogen, barium, manganese, and chromium are limited to but four or five minerals each and combined make up but about thirty-five one-hundredths of one per cent of all soil mineral matter. About ninety-seven per cent of all soil mineral is composed of eight elements, oxygen, silicon, sodium, potassium, calcium, magnesium, aluminium, and iron. The remaining five elements, hydrogen, sulphur, carbon, titanium, and phosphorus each occur in many important minerals or are active in mineral alteration and each composes from one-tenth to five-tenths of one per cent, by weight, of the inorganic part of the soil.

The occurrences, valences, and reactions of these elements are discussed only in so far as they are related to the soil minerals. Facts here given in connection with these properties are not intended to be applied to mineral conditions outside of the soil nor to the elements in the organic part of the soil.

Oxygen

Symbol O. Atomic weight 16. Valence 2. Slightly soluble in water. Combines directly with every known element except fluorine and the inert elements of the argon group.

Oxygen is the most abundant element in the earth's crust, composing by weight about 47.29 per cent of average igneous rock. It is a constituent of all abundant and important rocks of which it forms from 44 to 53 per cent.

Oxygen is an essential constituent of all the *common* soil minerals except the two iron sulphides, pyrite and marcasite. It is very abundant as the oxides of silicon and iron and also in the form of carbon dioxide and hydrogen monoxide, the two most

16

important agents of chemical weathering. It is a constituent of all carbonates, sulphates, and hydroxides, and is always present in the minerals containing silicon, aluminium, and magnesium, which are fully oxidized. It is also always present in the manganese minerals which may be partially or fully oxidized. The iron and sulphur of soil minerals may be wholly unoxidized, partly oxidized, or completely oxidized. The process of the oxidation of incompletely oxidized iron is one of the chief processes of mineral decomposition. Oxygen is a constituent of all acids commonly involved in mineral alteration except hydrochloric acid and hydrogen sulphide. The element is involved not only in oxidation but in the three other major decompositional processes, hydration, carbonation, and hydrolysis.

Hydrogen

Symbol H. Atomic weight 1.008. Valence 1. Very slightly soluble in water.

Hydrogen is an exceedingly widespread element in soil minerals and its activity is of great importance in the alterations of these minerals, but due to its extreme lightness a statement of its abundance gives but a small conception of its importance. By weight it forms 0.16 per cent of igneous rock.

The element is an essential constituent of limonite, diaspore, gibbsite, mica, epidote, kaolinite, serpentine, talc, chlorite, gypsum, and the bicarbonates, besides many less abundant and important minerals. It is also a constituent of soil organic matter and of all acids and water.

Hydration is the most widespread of decompositional reactions and the hydration of aluminium silicates is the characteristic reaction in the production of clay minerals. Moisture is essential to all rapid oxidation and carbonation.

Sulphur

Symbol S. Atomic weight 32.07. Valences 2, 4 and 6. Polymorphous. Insoluble in water.

Sulphur makes up 0.103 per cent of igneous rock. It occurs native, as sulphides, and as sulphates. Inorganic sulphur is largely associated with hydrogen, iron, and calcium.

Only three sulphur minerals of importance in soil studies occur in humid regions. These are pyrite and marcasite, both sulphides of iron, and gypsum, hydrous sulphate of calcium. Anhydrite sometimes is found as a product of the dehydration of gypsum. In "alkali" regions sulphates of sodium, magnesium and iron are fairly common soil minerals. These minerals are all highly soluble and when present in considerable quantities are injurious.

Native sulphur is formed either by volcanic action, by reduction of sulphates, or as a by-product liberated in the oxidation of iron sulphide. Hydrogen sulphide and sulphuric acid are two forms of sulphur in solution which are active in mineral alteration.

A sulphide may be easily determined by yielding a sublimate of sulphur in a closed tube. All sulphides redden moistened blue litmus paper in an open tube. A sulphate will not give a sublimate in a closed tube, but after fusion with soda and borax, if placed on a moist silver coin, it will cause a brown stain of silver sulphide.

Fluorine

Symbol F. Atomic weight 19.0. Valence 1. The most active of all elements. It combines directly with all elements except oxygen and the members of the argon group. *fluorite*

Fluorine occurs in only five soil minerals: ~~fluorine~~, hornblende, phlogopite, tourmaline, and apatite. In two of these, fluorite and apatite, it is present in considerable amounts and as a definite and essential part of the compound. In both minerals it occurs as a fluoride of calcium. In hornblende and tourmaline it is present in small varying amounts as a substitution element. In both these latter minerals calcium is present.

Through the decomposition of fluorite, and to a less extent of the other fluorine minerals, hydrofluoric acid is developed in minute amounts. This acid is important because of its action on silica and the silicates which are readily decomposed and dissolved by the formation of silicon tetrafluoride.

Fluorine may generally be identified by heating the mineral containing it in a closed tube with powdered potassium bisulphate and glass. The fluorine which is liberated will etch the

glass and form a white sublimate of silicon fluoride in the upper part of the tube.

Chlorine

Symbol Cl.   Atomic weight 35.46.   Valence 1.   Readily soluble in water.

Chlorine is a member of the halogen group of elements and together with fluorine the only members of that group occurring in soil minerals. The element occurs as chloride of sodium, both in solution in the soil water and as the mineral halite, as the chloride of magnesium in solution, and as the chloride of calcium in apatite. It is a constituent of many potash fertilizers in which it occurs as a chloride of the potassium.

Hydrochloric acid is one of the agents of mineral alteration and chloridation is a minor mineral decompositional process producing soluble salts.

Carbon

Symbol C.   Atomic weight 12.00.   Valence 4.   Allotropic.

Carbon, the characteristic element of organic compounds, plays a subordinate part to silicon in the minerals. In the soils its inorganic occurrence is limited to the carbonates and bicarbonates, and to carbon dioxide.

The characteristic and abundant carbonates are those of calcium, magnesium, and iron, and the double carbonates of the above bases. Soluble sodium and potassium carbonates are common in small amounts formed by the weathering of sodium and potassium silicates.

The bicarbonates, or acid carbonates, are easily formed from the normal carbonates. The commonest form of soluble iron compound in nature is the bicarbonate, and the bicarbonate together with the chloride and sulphate are the most common forms of soluble magnesium. The bicarbonate together with the sulphate are the most common forms of soluble calcium. The bicarbonate of sodium is less soluble than the normal carbonate and is the only bicarbonate commonly precipitated as a mineral. This is the ordinary "black alkali" mineral or trona.

Carbonation, effected chiefly by the agency of carbon dioxide, is one of the characteristic processes of mineral weathering. The immediate source of the carbon is from the atmospheric carbon dioxide or from living or decomposing organisms. The original source cannot be determined for certain, but may have been from volcanic exhalations, the decomposition of carbo-silicates, or oxidation of carbides.

Silicon

Symbol Si. Atomic weight 28.3. Valence 4. Allotropic.

Silicon is the most abundant mineral element except oxygen and it composes about 28 per cent of the earth's crust. It is found as an acid and as an oxide and forms silicates of all soil metals. Silicon is a constituent of all common soil rocks except the carbonates and oxides, and in these it is found very often as an impurity.

The common silicates are salts of metasilicic acid, H_2SiO_3, orthosilicic acid, H_4SiO_4, diorthosilicic acid, $H_6Si_2O_7$, and trisilicic acid, $H_4Si_3O_8$. Except for the feldspars, salts of trisilicic acid, most of the common silicates are derived from the metasilicic or orthosilicic acids. Silicic acid, colloidal silicates, and silica are the most common of the inorganic clay colloids.

The common silicates in order of abundance are those of aluminium, iron, magnesium, calcium, sodium, and potassium, Silicates of manganese, barium, and zirconium also occur. These compounds seldom exist separately but are generally combined several together to form double, triple, and highly complex silicates as the micas and tourmaline.

The most common and characteristic of the hydrous silicates are those of aluminium and magnesium. These have generally been formed in the soil through the hydration of the anhydrous silicates and the removal by oxidation or carbonation of the iron, calcium, sodium, and potassium.

Silicon dioxide, both crystalline and amorphous, is among the most common of minerals. The crystalline dioxide is soluble in alkaline water, but nearly insoluble in ordinary ground water. The amorphous form is more soluble and is frequently hydrous. The dioxide is often formed by the breaking down of the silicates.

Boron

Symbol B.   Atomic weight 11.0.   Valence 3.   Allotropic.
Boron is a constituent of two soil minerals, the sodium borate, borax, and the aluminium boro-silicate, tourmaline.

Titanium

Symbol Ti.   Atomic weight 48.1.   Valence 4.
Titanium is the most abundant of the more rare mineral elements, composing about 0.46 per cent of all igneous rock.   It is very widely distributed in small amounts, being known as a constituent of about 98 per cent of analyzed igneous rocks.

The element is found as a titanate of iron in ilmenite and as an oxide in rutile.   Titanium is a common replacing element of iron in magnetite, hematite, limonite, and biotite.   It is usually most abundant in soils containing high percentages of iron.

Titanium may be determined in minerals by fusing on platinum in a bead of sodium ammonium phosphate.   The bead is then dissolved in a 30 per cent solution of sulphuric acid with a few drops of nitric acid added.   On the addition of a little hydrogen peroxide to the solution a deep yellow color proves the presence of titanium.

Zirconium

Symbol Zr.   Atomic weight 90.6.   Valence 4.
A rare element closely related to titanium and found as a silicate in zircon.

Nitrogen

Symbol N.   Atomic weight 14.01.   Valence 3.
Although an important constituent of the air and organic matter nitrogen is of rare occurrence as a mineral element.   It is found as the nitrate of sodium and the nitrate of potassium. Neither of these is a common mineral.

Phosphorus

Symbol P. Atomic weight 31.04. Valence 3. Allotropic. Insoluble in water.

Phosphorus is very widespread in small amounts as the crystalline phosphate of calcium (apatite), and as the amorphous calcium phosphate (collophanite). It also occurs as the ferrous phosphate (vivianite). These phosphates are all salts of the orthophosphoric acid H_3PO_4.

If a phosphorus mineral is placed on a clean platinum wire, moistened with sulphuric acid and burned a greenish-blue flame is produced. If a phosorus mineral is ground with one part of sodium nitrate and two to three of sodium carbonate, fused, the fused mass dissolved in nitric acid, and an excess of ammonium molybdate added a yellow precipitate will be formed.

Sodium

Symbol Na. Atomic weight 23.00. Valence 1.

Sodium is of very common occurrence both as a mineral constituent and in solution. It composes about 2.5 per cent of all mineral matter. It is most abundant as the trisilicate of sodium and aluminium in the plagioclase feldspars. It is also important as an orthosilicate in nephelite, and as a metasilicate in hornblende, zeolite, and some varieties of pyroxene. Next to its occurrence as a silicate it is most abundant as the chloride, halite. Nearly all soil and river waters contain traces of this compound in solution.

In the weathering of sodium silicates the metal is usually liberated as the soluble carbonate which may alter to the less soluble bicarbonate. This latter may be precipitated as the mineral trona.

Sodium occurs as the sulphate forming mirabilite and as the nitrate in soda nitre. Both of these latter minerals are "alkali".

It is present in solution in nearly all natural waters, the ratio of sodium to calcium rising rapidly as the climate becomes more arid.

The simplest test for sodium in minerals is the bright yellow flame imparted by burning on a platinum wire. If the mineral

is a silicate the flame test may be accentuated by treating as explained in the introduction to the determinative tables.

Potassium

Symbol K. Atomic weight 39.1. Valence 1.

Potassium occurs in nearly the same relations as sodium and is nearly as abundant. It is common as the trisilicates of potassium and aluminium (orthoclase and microcline), as an orthosilicate in micas and zeolites, and in solution in ground water. From the silicates it is generally liberated by weathering as the soluble carbonate or hydroxide.

Potassium occurs as a chloride in sylvite, carnallite, and kainite. These minerals are of very limited distribution but are of value as fertilizers. It is also found as the nitrate, saltpeter.

The potassium of soil minerals may be identified when present by the violet color imparted to the flame.

Calcium

Symbol Ca. Atomic weight 40.07. Valence 2.

Calcium composes about 3.5 per cent of all soil mineral material. It is found in a very great variety of combinations. As a silicate it is a constituent of plagioclase, hornblende, tremolite, actinolite, pyroxene, epidote, garnet, and zeolite. In these compounds it is associated with the bases aluminium, iron, magnesium, sodium, and potassium. It is very abundant as a carbonate in which form it is commonly associated with magnesium. It is the most important sulphate base, occurring as the anhydrous sulphate (anhydrite), and as the hydrous sulphate (gypsum). Calcium phosphate is widely distributed both in crystalline and amorphous form, nearly all inorganic phosphorus being in the form of calcium phosphate. Calcium readily combines with fluorine, forming the fluoride in both fluorite and apatite.

Calcium is the most abundant metal in solution in ground water. The calcium in solution is very largely in the bicarbonate and sulphate forms, although the normal carbonate, phosphate, and fluoride are not entirely insoluble. Calcium sulphate has been termed the most abundant soluble salt in clays.

In the weathering of silicates calcium is rapidly removed by carbonation. The percentage loss of calcium from the weathering of acid rocks is much higher than the percentage loss of magnesium. In the weathering of basic rocks the percentage losses of the two are about equal.

Barium

Symbol Ba. Atomic weight 137.37. Valence 2.

Barium occurs in minute quantities in silicates, especially feldspar and mica, as a replacing metal of potassium, sodium, or calcium. On the weathering of the silicate it is liberated as a carbonate, sulphate, or chloride. The latter is soluble. Among the products of weathering it is often found associated with manganese hydroxide.

Magnesium

Symbol Mg. Atomic weight 24.32. Valence 2.

Magnesium is a very abundant and widespread metal occurring in nearly all kinds of combinations found among the soil minerals.

The only important group of silicates of which magnesium is not a constituent is feldspar, and it is here often found as an impurity in small proportions. It is, next to aluminium, the most abundant metal of the hydrous silicates, being less rapidly desilicated in the weathering processes than iron or calcium. Its most constant associates among the silicates are: first, iron, and second, calcium, either of which it easily replaces or is replaced by.

Among the minerals produced by weathering agencies the most common associating base is calcium. Magnesium is found as a carbonate by itself and as a double carbonate with iron, but most commonly as a double carbonate of calcium and magnesium.

As an hydroxide magnesium occurs in clays often associated with iron and manganese hydroxides.

The sulphate and chloride are less common minerals than the carbonate, but are readily soluble and abundant in natural waters which are rarely free from them. Magnesium is the sec-

ond most abundant metal in solution in both ocean and land waters.

Magnesium is most easily recognized in the minerals by the pink color produced with cobalt nitrate solution.

Aluminium

Symbol Al. Atomic weight 27.1. Valence 3. Specific gravity 2.6 to 2.7. Electric conductor. Chemically rather inert.

This is by far the most abundant metal and the third most abundant element in mineral matter, of which it makes up about 8 per cent.

Among the anhydrous silicates aluminium occurs with potassium, sodium, and calcium to form the feldspars. As a silicate with potassium, magnesium, and iron it forms the micas. As a silicate with magnesium, iron, and calcium it composes hornblende and pyroxene.

Hydrous silicates and hydroxides of aluminium are among the most important of the clay minerals. In weathering the element is always hydrated and as it is not easily desilicated the hydrous silicate becomes the most characteristic of the clay minerals. The hydrous oxide, diaspore, and the hydroxide, gibbsite, are formed by extreme weathering which results in the desilication of the metal. These compounds are particularly important soil minerals in warm, moist climates where decomposition is complete.

Aluminium is important in colloidal matter. Colloidal silicates, silica, alumina, and ferric oxide, in the order named, are the most abundant of the mineral colloids of clay.

The aluminium compounds are the least soluble of any of the mineral compounds and are commonly considered as the constants from which the calculations of the additions and subtractions of matter in weathering are made.

Aluminium heated with soda swells and forms an infusible compound. With borax a clear or cloudy bead is formed. For infusible compounds treatment with cobalt solution is a convenient method of testing for the presence of the element.

Iron

Symbol Fe. Atomic weight 55.84. Valences 2 and 3. Specific gravity 7.86. Malleable. Ductile. Magnetic.

Iron is, next to aluminium, the most abundant element, and is found as a constituent of practically all rocks and soils.

As a silicate both ferrous and ferric iron is abundant but the ferrous is the more common. Ferric iron often occurs in silicates as a replacing metal of aluminium. Ferrous silicate is generally associated with magnesium silicate, less often with calcium silicate. Hydrous silicate of iron is not common, due to desilication of the iron in the hydrating process.

The desilication of iron with its oxidation and change from ferrous to ferric form is one of the chief processes of the weathering of rock to soil. Ferric oxides and hydroxides are insoluble and are among the most common of the soil minerals. They occur as nodules, grains, pulverulent material, cements, and colloidal matter. Among the inorganic colloids of clay they are very important.

Iron disulphide is common as pyrite and marcasite. It is easily alterable by oxidation of the sulphur to the soluble ferrous sulphate, an injurious soil constituent.

Ferrous carbonate, or siderite, is an important product of the alteration of iron minerals and is particularly abundant in bog deposits. It is readily alterable by the action of water charged with carbon dioxide into soluble ferrous bicarbonate, the most important form of soluble iron. The deposition of iron is largely due to the reversion of the bicarbonate to the normal carbonate.

Iron is determined in the minerals by the yellow to red color imparted to the borax bead in the oxidizing flame and the green color obtained with the reducing flame. Many of the iron minerals become magnetic when heated with soda on charcoal.

Manganese

Symbol Mn. Atomic weight 54.93. Valences 2 and 4.

Manganese is very widely distributed but in small amounts. It occurs as a metasilicate most frequently in pyroxene. It is sometimes found as an orthosilicate replacing magnesium or iron orthosilicate. It also occurs as an oxide impurity in silicates.

In weathered soils, if present, it is usually as the dioxide, pyrolusite, or the hydroxide, psilomelane. These minerals com-

monly accompany either the iron minerals or the phosphates. They are more concentrated in moist than in dry soils.

The characteristic test is the amethystine borax bead.

Chromium

Symbol Cr. Atomic weight 52.0. Valence 3.

Chromium is found chiefly as iron chromite occurring in minute quantities widely distributed. The compound is very stable under weathering conditions.

CHAPTER III

THE WEATHERING OF MINERALS

PRINCIPLES INVOLVED

The inorganic part of the soil is the result of the weathering of the rocks and rock minerals. Weathering is an adjustment to the environment found at or very near the earth's surface. Let us consider a mineral in granite a few thousand feet below the surface. This mineral will be hard, solid, dense, and chemically stable. So long as it remains in its present environment it is permanent because its environment is fixed and it is fully adjusted to it. If now erosion of the overlying rock brings it to the surface a new environment is entered. It is released from the pressure of the overlying rock, its average temperature is reduced, and for the first time it is exposed to the activities of the atmosphere, water, and the chemicals of the soil. The reaction toward this environment is one of replacing the old mineral combinations of the granite by new ones more stable under the new conditions. This reaction is both physical and chemical and is called weathering because it is largely produced by the atmosphere and atmospheric agents. In general terms it may be said that minerals of high density, laminated structure, and with silicate radicals are the most stable under the temperatures, pressures, and chemical conditions deep below the surface, while minerals of lesser density, amorphous or granular structure, and which are highly oxidized and hydrated are the most stable under surface conditions. This statement, however, is a very generalized one and shows merely a tendency rather than an accomplished condition.

The general results of weathering consist of the separation of silica and the bases, the carbonation of the bases, the hydration of the remaining silicates, the alumina and the iron, the oxidation of ferrous to ferric iron, the production of lower

28

specific gravities, and an increase in bulk. The processes of weathering and their agents may be considered as falling into two groups: (1) the physical, or disintegrating, and (2) the chemical, or decomposing. It should be borne in mind that neither of these two sets of processes goes on without the co-operation of the other. The higher the altitude, the steeper the slope, the drier the climate, and the cooler the season the larger the ratio of the disintegrating to the decomposing processes. The opposite conditions increase the proportion of the decomposing processes, but neither ever works to the exclusion of the other. So far as the results of the two may be separated gravels and sands are largely the products of disintegration while the products of decomposition are clays, colloidal and cementing materials, and soluble salts.

THE DISINTEGRATION OF MINERALS

Mineral disintegration is accomplished by wind and water abrasion, frost action, expansion and contraction under temperature changes, and the wedge work of roots.

Abrasion is carried on not by wind and water themselves, but by the rock fragments which they carry. The rate at which mineral aggregates, or rocks, may be broken down by this process is proportional to the strength and constancy of the current, its supply of rock fragments, and the strength of the cementing materials of the rock or the cohesion among the crystals. The rate of wear on a single crystal is influenced by the hardness of the mineral, its tenacity, structure, and cleavage.

Frost action is very effective on porous mineral masses or on single minerals of micaceous or fibrous structure if they have been exposed long enough for the structural parts to begin to separate. Frost action, while locally of great importance, is not so great a factor in soil formation as is generally supposed. This is because it is limited in its climatic and seasonal activity, and because it is not effective at great depths.

Expansion and contraction from temperature change is not effective on single crystal fragments except when the cleavage surfaces of thinly laminated minerals are exposed. In this case the outer laminae in expanding and contracting will slip over the inner and eventually flake off. The process is very effective,

however, in the breaking down of mineral aggregates, particularly if the aggregate consists of several kinds of minerals with different coefficients of expansion.

Wedge work of roots is an important factor in prying apart mineral masses especially if the masses be fissured or jointed. The work accomplished by this agency is far greater than anyone without considerable field experience will realize.

Disintegration by any of these agencies is an important stimulus to decomposition through opening up the rock and soil to the entrance of air and ground water and also through exposing greater mineral surface to the decomposing agents.

THE DECOMPOSITION OF MINERALS

The chief decompositional processes are hydration, carbonation, oxidation and hydrolysis. To these may be added the much less important processes, from the soil-formation standpoint, of reduction, sulphation, and chloridation. These processes do not act consecutively or independently, but are simultaneous and interlocking.

Hydration

Hydration is a constant accompaniment of mineral decomposition. It may be effective as a process by itself produced through the agency of pure water, but in nature it is always accompanied by other decompositional processes.

Hydration is the most extensive weathering reaction and affects all classes of minerals. Nearly all minerals of the soil are either hydrous compounds or are found in a more or less decomposed condition due to hydration. The amount of decomposition due to hydration is dependent upon the climatic conditions, the chemical composition, and the length of time during which the mineral matter has been exposed.

The initial stage in the process of decomposition of an igneous mineral may be represented by the carbonation of the calcium, magnesium, potassium, and sodium, the oxidation of the iron, and the hydration of the aluminium and much of the silicon. The carbonates and oxides thus formed are susceptible to later hydration.

Dehydration is a process which occurs in arid regions or in long continued hot, dry seasons in humid regions. It does not seem to be effective in measurable amounts on hydrous silicates but is important in the results produced on ferric hydroxides. These results may be easily observed in the production of red colors in the surface soils while the subsoils retain the yellows of the hydrated iron. This dehydration is responsible for much of the red of desert soils and the red near the surface in many of our southern states. Dehydration and decarbonation of the bicarbonates are produced by decrease in pressure and by the action of living organisms and are very important factors in the precipitation of these compounds.

The effects of hydration are: (1) decrease in hardness, (2) decrease in density, (3) liberation of heat, and (4) increase (usually) in solubility.

The decrease in hardness produced by hydration is marked. The average hardness of nine common anhydrous soil minerals which are easily hydrated is 6.1. The average hardness of the six most common soil minerals formed by the hydration of the above is 3.7. This decrease in hardness is important in its results on mineral disintegration.

Decrease in density produced by hydration is greater than the decrease produced by carbonation. The average specific gravity of the common anhydrous soil silicates is 3.01 and of the common hydrous soil silicates 2.64.

The amount of heat liberated through hydration is considerable but cannot be quantitatively stated.

Carbonation

The chief agent of carbonation is carbon dioxide with water, or carbonic acid, although undoubtedly other organic acids are instrumental in an undetermined degree.

Carbonation in conjunction with hydration, or with hydration and oxidation, is effective on both hydrous and anhydrous silicates, and on sulphides and sulphates, especially of ferrous iron. In conjunction with reduction it is effective on the oxides and hydroxides of iron. The carbonation is accomplished chiefly by the substitution of carbonic for silicic acid, but to a small

extent by the substitution of carbonic for other acid radicals or for oxygen.

The main source of carbon dioxide is from the atmosphere where it is present by weight in about the proportion of 45 parts in 100,000. From the atmosphere it is dissolved by rain water and washed into the soil and upper rock strata, or is taken up by vegetation and thence carried into the soil where it is concentrated in larger amounts than in the atmosphere. Where the climate is humid and vegetation abundant the concentration of carbon dioxide is greater and the process of carbonation of the minerals more active than where the climate is dry and vegetation scanty.

Carbonation is stimulated by increase of temperature and increase of pressure. Under the normal temperatures and pressures existing near the surface carbonation is a more active process than silication and the tendency is to the production of carbonates through the carbonation of the bases and the setting free of silica or silicates. Deeper below the surface, with increase of heat and pressure, the activity of silicic acid increases more rapidly than that of carbonic acid and the process of carbonation is reversed and the bases are silicated.

In the carbonation of the silicates those of calcium and magnesium are most readily attacked. Potassium and sodium silicates become carbonated more slowly, yielding alkaline carbonates with by-products of silica and silicates. While iron readily forms a carbonate its easy oxidation is a hindrance to the production of iron carbonate commensurate in amount with the calcium and magnesium carbonates by carrying most of it over to the oxide and hydroxide forms.

The presence of calcium carbonate and the alkaline carbonates is a great stimulus to the carbonation of silicates at soil temperatures and pressures. Carbonation is, therefore, a self-accelerating process, becoming more rapid as the carbonates accumulate.

Carbonation is both a volume increasing and a heat liberating reaction. The increase in volume, if no material were removed by solution, would range from about 15 to 50 per cent. In rare cases the range would be more extreme but this is the normal. The process is also in the direction of increased solubility of the bases affected. In humid areas the carbonates are

removed from the soil in general about as rapidly as formed, but in arid regions they accumulate and give rise to ''alkali'' soils in which the amount of ''alkali'' rapidly increases to the point of reduction and final prevention of growth of vegetation.

Oxidation

The most important oxidation changes in the decomposition of minerals in the soil are those of the oxidation of ferrous to ferric iron, and of the sulphur of sulphides to that of sulphates. Oxidation without accompanying hydration often takes place, but it is more commonly accompanied by the latter process.

Ferrous iron is an essential constituent of pyrite, marcasite, siderite, magnetite, biotite, hornblende, some varieties of pyroxene, chlorite, and many silicates of less abundance in the soil. It is also generally present either as an impurity or by replacement in many silicates and in the carbonates of calcium and magnesium. In all these compounds, except magnetite, the ferrous is readily oxidized to ferric iron. The reaction may be purely chemical or bio-chemical. The oxidation of iron minerals is accompanied by: (1) liberation of heat, (2) increase of volume when silicates are affected, (3) decrease in volume when carbonates are affected, (4) production of red and yellow colors, and (5) decrease in solubility when acting on the carbonate.

The sulphide minerals which are common are pyrite and marcasite with which may be included hydrogen sulphide. Oxidation of the sulphur of these products produces iron and hydrogen sulphates which are highly soluble. The iron sulphate is an injurious soil mineral which fortunately, because of its great solubility, seldom accumulates. In the oxidation of iron sulphide, hydrogen sulphide or sulphurous acid may be liberated which is then oxidized to sulphuric acid.

Oxidation is effective on manganese, which in igneous rocks is generally found as manganous silicate but in the soil is oxidized to the manganic or the quadrivalent forms.

Hydrolysis

Hydrolysis, or hydrolytic dissociation, is the double decomposition of water and a salt. This is followed by the reas-

sembling of their ions into a free acid and a free base. The apparent reaction is as follows:

$$Na_2CO_3 + 2H_2O = 2NaOH + H_2CO_3.$$
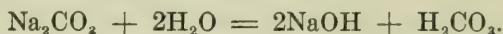
In this reaction the actual change is the strong ionization of the sodium carbonate as: $Na_2CO_3 \rightleftharpoons 2Na^+ + CO^-_3$, and the weak ionization of the water as: $2H_2O \rightleftharpoons 2OH^- + 2H^+$. These dissociation products reassemble as sodium hydroxide and carbonic acid.

As the carbonic acid weakly ionizes it effectually ties up the positive hydrogen ions while the strong ionization of the sodium hydroxide leaves free many of the negative hydroxyl ions which give to the solution an alkaline character. In this case the reacting salt was composed of a strong basic and a weak acid radical. If the reacting salt is composed of a weak base and a strong acid radical, as ferric chloride, the resulting solution will show an acid reaction.

In the processes of the decomposition of mineral matter to soil, water is always present as the principal solvent of the reacting substances. As minute amounts of this water are continuously ionized hydrolytic decomposition is universal, both in time and place, except in thoroughly desiccated soils. As an important factor in mineral weathering, therefore, we have the universal phenomenon: salt + water $\rightleftharpoons$ acid + base. In mineral decomposition the acid radicals involved are chiefly the weak silicic and carbonic and less frequently orthophosphoric and the strong hydrochloric, sulphuric, and (in soils) nitric. The reacting bases are weak aluminium and iron, calcium, and the strong potassium, sodium, and (in soil) ammonium ions.

Hydrolysis is, therefore, of exceeding importance because of its influence on the acidity or basidity of the environment in which mineral weathering occurs. Water thus plays four distinct roles in mineral decomposition: (1) as a solvent, (2) as a combining chemical in hydration, (3) as one of the requisite compounds in hydrolysis, and (4) as a catalytic agent.

Reduction

The process of reduction is the opposite of that of oxidation and is sometimes referred to as deoxidation.

The chief agents of reduction are decomposing vegetation, bacteria, and the organic acids, important among which are humic and ulmic acids. Reduction is a process of mineral weathering only in areas in which the soil is so covered or saturated with water as to exclude circulation of air for most of the time. Under these conditions the demands for oxygen by oxidizing bacteria and decomposing vegetation will cause its extraction from oxidized minerals. The process is most active on oxidized iron and sulphur minerals. Iron carbonate, iron sulphide, and sulphur are the chief products of these reduction processes.

Sulphation

The addition of sulphur to a base in the process of weathering is accomplished by the agency of sulphuric acid or of some sulphide or sulphate as iron sulphate. The only minerals of importance formed by sulphation are anhydrite, gypsum, pyrite, and marcasite. The first two are frequently formed by the sulphation of calcium compounds, probably the carbonate.

Chloridation

Chloridation, or the addition of chlorine, is a minor process of mineral decomposition produced through the agency of hydrochloric acid or the interchange of bases between a chloride and another mineral. The chlorides of sodium and magnesium are the most common. The process increases the solubility of the base.

PART II

DETERMINATIVE MINERALOGY

The accompanying key is based on the common blowpipe methods well known to all students and teachers of mineralogy. The attempt has been made to keep the methods and equipment as simple as is consistent with the accurate determination of the species included and thus render the book practical for use in agricultural geology courses having but little time to devote to mineralogy work and for soil research workers who have had little mineralogical training.

Tests for elements.—Tests for the various elements as iron, magnesium, etc., will be found under the treatment of the element in Part I, Chapter II.

Physical properties.—The various physical properties referred to will be found explained under their proper heads in Part I, Chapter I.

Burning.—Some minerals, as pyrite, when treated for fusion take fire and burn as long as the blowpipe flame is directed upon them.

Flame colors.—These are obtained by turning the blowpipe flame on a small chip or a little powder of the mineral held on a clean platinum wire. The color is often accentuated by moistening the mineral with a drop of hydrochloric acid.

Flame color for silicates.—The potassium or sodium flame of a silicate containing these elements may be satisfactorily determined by grinding the powdered mineral with calcium sulphate and moistening with hydrochloric acid.

Magnetic residue.—This is a test for iron. The mineral is powdered, mixed with powdered soda, and fused on a stick of charcoal or with powdered charcoal on a platinum foil.

Borax bead test.—The test is made by dipping a clean platinum wire with a small loop at one end into borax and fusing to a clear bead. The bead while hot is touched to a grain

of the mineral to be tested and heated again until thoroughly fused. Care should be taken to use only a small amount of mineral in each bead and to fuse until it is of a uniform color throughout.

Gelatinization.—Many silicates when treated with acid liberate a gelatinous silica. The mineral should be finely powdered, placed in a test tube and treated with hydrochloric acid and allowed to stand until a thick jelly forms. Boiling will hasten the gelatinization in some cases. Some minerals will gelatinize after the powder has been fused, but not before.

Fusion.—The fusibility of a mineral may be tested by taking a fine splinter and holding in platinum-tipped forceps in such a manner that the end of the splinter projects freely beyond the forceps. The blowpipe is then inserted in the edge of a Bunsen burner flame and the flame blown out into a horizontal cone. The splinter should be held just beyond the tip of the blue flame which should be directed steadily upon it (Fig. 5). The splinter should be examined with a hand lens both before and after heating, as in the more difficultly fusible minerals there will be shown only a slight rounding of the point or edges.

Water in a closed tube.—Some minerals when powdered and placed in the bottom of a small tube of hard glass closed at one end, and heated give off water which may be observed as steam issuing from the top of the tube. If the tube is held in a slanted position with the top well out of the flame the moisture will condense on its sides.

Cobalt solution.—This is a ten per cent aqueous solution of cobalt nitrate. If a light-colored, infusible aluminium mineral is pulverized and strongly heated on platinum, moistened with the cobalt solution, and then heated again, a blue color will be obtained. Under like treatment infusible magnesium minerals will give a pink color.

ABBREVIATIONS USED IN THE TABLES

Cleav.	Cleavage.	**Mag.**	Magnetic.
Con.	Concentrated.	**Mass.**	Massive.
Decom.	Decomposed.	**Reac.**	Reactions.
Dil.	Dilute.	**Rt. ang.**	Right angles.
Effs.	Effervesces or effervescence.	**Sol.**	Solution or soluble.
Fus.	Fusible.	**Sp. g.**	Specific gravity.
Gran.	Granular.	**Sul.**	Sulphate.
Hard.	Hardness.		

Key to the Determination of Species

Lustre	Sp. g.						Species
Metallic lustre	Sp. g. 3–4	Becomes magnetic after fusion					Limonite
		Amethystine bead with borax					Psilomelane
	Specific gravity 4–5	Magnetic residue with soda	No water in closed tube	Burns before blowpipe	Completely dissolved by HNO_3		Pyrite
					Not as above		Marcasite
				Reactions for Ti			Ilmenite
				No reaction for Ti	Black streak		Magnetite
					Red streak		Hematite
			Water in closed tube	Red streak			Turgite
				Yellow streak	Sp. g. over 4		Goethite
					Sp. g. under 4		Limonite
		Reactions for manganese	Hardness above 4				Psilomelane
			Hardness below 4				Pyrolusite
		No reactions for manganese or iron					Rutile
	Sp. g. over 5	Sulphide reactions					Pyrite
		No sulphide reaction	Reactions for Ti				Ilmenite
			No Ti reaction	Streak red			Hematite
				Streak black			Magnetite
Non-metallic lustre	Sp. g. less than 2	Hard					Opal
		Soft	Potassium reaction	Pink with cobalt sol.			Carnallite
				Not as above			Sylvite
			Sulphate reaction	Sodium flame			Epsomite
				Becomes magnetic			Copperas
				Pink with cobalt sol.			Mirabilite
		Fuses with intumescence giving yellow color to flame					Borax
	Specific gravity between 2 and 3	Hardness less than 3	Readily soluble in water	Yellow flame	Effs. in HCl		Trona
					Does not eff. in HCl		Halite (cubic cleav.)
							Soda nitre (indefinite cleav.)
				Violet flame	Sul. reac.		Kainite
					No sul. reac.		Nitre
			Insoluble in water but affected by HCl	Scaly	Hard. 2.5+		Serpentine
					Hard. 2.5−		Chlorite
				Fibrous	Sul. reac.		Gypsum
					Blue with cobalt sol.		Gibbsite
					Pink with cobalt sol.		Serpentine (Hard. 2.5+)
							Brucite (Hard. 2.5−)
				Foliated	Pink with cobalt sol.		Serpentine (Hard. 2.5+)
							Brucite (Hard. 2.5−)
					Not pink with cobalt sol.		Gypsum (Sul. reac.)
							Chlorite (Dark green)
				Not distinctly scaly, fibrous or foliated	Green	Mass.	Serpentine
						Gran.	Glauconite
					Not green	Eff.	Calcite
						No eff.	Gypsum

KEY TO THE DETERMINATION OF SPECIES—*Continued*

Lustre	Sp. gravity	Hardness	HCl	Group					Species
Non-metallic lustre—*Continued*	Specific gravity between 2 and 3—*Continued*	Hardness less than 3—*Continued*	Not affected by HCl	Micaceous	Decom. by hot H₂SO₄	Fe reac.			Biotite
						No Fe reac.			Phlogopite
					Not as above				Muscovite
				Not micaceous	Fus. to a mag. mass.	Test for P			Vivianite
						No P test			Glauconite
					Not fus. to a mag. mass.	Pink with cobalt sol.			Talc
						No Mg reac.			Kaolinite
		Hardness from 3 to 6	Sol. in H₂O	Effs. with HCl					Trona
				Sulphate reaction					Kainite
			Affected by HCl	Effervesces	Effs. freely in cold or dil. HCl	Sp. g. 2.75−			Calcite
						Sp. g. 2.75+			Aragonite
					Effs. in hot or conc.				Dolomite
				Gelatinizes	Violet flame				Apophyllite
					Sodium flame	Hard. 5+			Nephelite
						Hard. 5−			Analcite
				Dissolves only	Infusible	Sp. g. 2.5+			Serpentine
						Sp. g. 2.5−			Gibbsite
					Easily fusible	H₂O in closed tube			Stilbite
						No H₂O in closed tube			Anhydrite
			Not affected by HCl	Yields water in closed tube					Opal
				Cleavage at right angles					Orthoclase
				Cleavage not at right angles	Reactions for K				Microcline
					No potassium reactions	Sp. g. 2.65+	Light		Oligoclase
							Dark		Labradorite
						Sp. g. 2.65−			Albite
				Columnar or bladed	Nearly black				Hornblende
					Gray				Tremolite
		Hardness 6 or above	Gelatinizes with HCl						Nephelite
			Not affected by HCl	No cleavage	Water in closed tube				Opal
					No water in closed tube	Glassy			Quartz
						Not glassy			Chalcedony
				Cleavage present	Cleavage at or nearly at right angles	Reactions for potassium			Orthoclase (Cleav. at rt. ang.)
									Microcline (Cleav. nearly at rt. ang.)
						Reactions for Na	Sp. g. over 2.65		Oligoclase (light color)
									Labradorite (Dark color)
							Sp. g. 2.65−		Albite
				Bladed or columnar	Nearly black				Hornblende
					Light color				Tremolite
	Specific gravity 3 to 4	Hardness below 5	Effs. in HCl	In cold dil. acid	Phosphorus reaction				Dahllite
					No P reaction				Aragonite
				In hot or conc. acid	iron reactions				Siderite
					No iron reactions				Magnesite
			Dis. in HCl	Reactions for phosphorus					Collophanite
				No P reaction	Fluorine reaction				Fluorite
					Sulphate reaction				Anhydrite
			Not affected by HCl						Biotite

KEY TO THE DETERMINATION OF SPECIES—*Continued*

Non-metallic lustre—*Continued*	Specific gravity 3 to 4—*Continued*	Hardness 5 to 7	Columnar or bladed	Cleavage near right angles				Pyroxene
				Cleavage at high angles	Black or nearly so			Hornblende
					Green			Actinolite
					White or gray			Tremolite
			Not columnar or bladed	No reaction for phosphorus	Powder gelatinizes with HCl after heating	Infusible		Olivine
						Fusible		Epidote (Soluble)
								Garnet (Insoluble)
					Powder does not gelatinize with HCl	Reac. for iron	Partly sol. in HCl	Hypersthene
							Insol. in HCl	Pyroxene
						No reaction for iron		Pyroxene (Fusible)
								Enstatite (Infusible)
				Reaction for phosphorus	Crystalline	Effervesces in HCl		Dahllite
						Sol. in HCl without eff.		Apatite
					Amorphous			Collophanite
		Hardness over 7	Columnar or bladed					Tourmaline
			Granular or in eroded crystals	Infusible				Olivine
				Fusible	Sol. in HCl			Epidote
					Insoluble in HCl			Garnet
	Sp.g. 4+	Fusible						Garnet
		Infusible						Zircon

DESCRIPTIONS OF MINERAL SPECIES

1. HALIDES

Halite

Halite, NaCl, or rock salt, occurs as a white or slightly colored mineral. Translucent to transparent. Streak white. Cleavage cubic. Brittle. Soluble in water. Easily fusible.

The mineral is of very wide distribution and is the only chloride of importance as a rock-forming mineral. It occurs both as a deposit in beds and as a dissolved salt in water. In amounts greater than one-fourth of one per cent it is an injurious soil ingredient for most crops. In quantities greater than one-half of one per cent it is sufficient to prevent nitrification. Dissolved in soil water it reduces vapor tension and thus lowers the rate of evaporation.

Carnallite

Carnallite occurs as a mixture of potassium and magnesium chlorides with water. $KCl \cdot MgCl_2 \cdot 6H_2O$. When pure it contains 14.1 per cent potassium.

It occurs in massive or granular form. Color white, or reddish. Taste bitter. Very deliquescent. Conchoidal fracture. Easily fusible, coloring the flame violet.

Carnallite is a valuable fertilizer and is used in the manufacture of potassium salts. A hot, saturated solution is formed in which the KCl and $MgCl_2$ separate and on cooling the less soluble potassium chloride crystallizes out.

Sylvite

KCl, (K 52.4 per cent). Sylvite is nearly pure potassium chloride but it generally contains some admixture of sodium chloride.

It is found in white or colorless granular or cleavable masses at the Stassfurt salt deposits. It has a hardness of 2 and a specific gravity of 2. The taste is distinctly salty.

The mineral is a valuable fertilizer.

Fluorite

Calcium fluoride, CaF_2. Calcium 51.1 per cent, fluorine 48.9 per cent.

Cleavage perfect. Lustre vitreous. Hardness 4. Color usually white, green or blue. Fusible. Soluble in sulphuric acid.

Fluorite is not of common soil occurrence, it is found as occasionally distributed grains in limestone soil or in soil residual from rocks containing ore veins. The inclusion of free fluorine may give rise to hydrofluoric acid which reacts with silica.

2. SULPHIDES

Pyrite (Iron pyrites, Fool's gold)

FeS_2. Iron disulphide. Iron 46.7 per cent, sulphur 53.3 per cent.

Color pale yellow to brass yellow with a greenish cast sometimes observed. Becomes brownish on tarnishing. Streak greenish-black. Lustre metallic. Brittle. Cleavage rarely developed. Irregular to conchoidal fracture. Hardness 6 to 6.5. Specific gravity 4.9 to 5.2. In crystals which are most frequently cubic in form and striated or dodecahedral. Other geometric forms may occur. The crystals vary in size from microscopic to several inches across and occur singly or in aggregates or drusy masses.

Fusible to a magnetic globule. On ignition will burn with a blue flame liberating SO_2. Insoluble in HCl. Soluble in HNO_3. Sulphur sublimate in a closed tube.

Pyrite alters in contact with oxygen and moisture to iron sulphate. The alteration to iron oxides is also common, the change taking place directly or through the temporary formation of ferrous sulphate. In regions of abundant oxygen in the soil the reaction is:

$$4FeS_2 + 22O + 3H_2O = 2Fe_2O_3 \cdot 3H_2O + 8SO_2 + k.$$
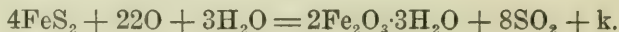
In soils pyrite frequently has a detrimental effect through its easy alteration to injurious ferrous sulphate. It serves as an important source of sulphuric acid in the soil.

Marcasite (White iron pyrites)

FeS_2. Of the same chemical composition as pyrite but differing from it in its physical and crystalline properties.

Color pale yellow or yellowish gray, a greenish tinge is frequent. Streak black. Lustre metallic. Hardness 6 to 6.5.

The mineral oxidizes more readily than pyrite and therefore is often more injurious than pyrite in soil.

3. OXIDES

Quartz

SiO_2. Si 47.7 per cent, O 52.3 per cent.

Colorless or white. With the presence of impurities it may become black or assume any color. Streak white. Vitreous or sometimes oily. Very brittle. No cleavage, fracture conchoidal. Hardness 7. Specific gravity 2.65. Occurs as massive striated crystals or as shapeless masses. In soils commonly as eroded grains or fragments.

Infusible without a flux. Fusible with soda with effervescence to a clear bead. Insoluble in acids except hydrofluoric. Slowly soluble in borax and potassium hydroxide.

Common varieties are:

> Rock crystal. Pure, colorless, and crystalline.
> Milky quartz. White, opaque or translucent. Glassy.
> Amethyst. Purple to violet in color due to the presence of manganese. Fine fracture lines usually present. Generally in crystals.
> Rose quartz. Pink or rose color due to titanium or manganese. Usually massive.
> Smoky quartz. Dark brown to black in color due to the presence of carbon compounds.
> Ferruginous quartz. Opaque brown or red crystals. Sometimes drusy.

The mineral is one of the most stable of compounds. End-products of chemical weathering do not occur.

Quartz is by far the most important mineral of sand and sandy soils. In cases of extreme weathering, except from rocks of peculiar type, it is the only mineral found in the sand. It is of great importance in clay and loam soils in giving open, porous texture. It is a mineral of piezo-electrical properties but it is questionable how great a part this plays in soils.

Chalcedony

SiO_2. A little ferric oxide and water is common.

Color very variable. Streak white. Lustre oily, waxy, or dull vitreous. Brittle. No cleavage, fracture conchoidal. Hardness 7. Specific gravity 2.6 to 2.65. Occurs in a great variety of structures as fibrous, botryoidal, compact, and massive but never in distinct crystals.

Tests the same as for quartz but more readily soluble in KOH. Varieties:

> Jasper. Opaque. Brown, red, or yellow in color. Contains much iron admixed with clay.
> Flint. Smoky to nearly black nodules and concretions. The coloring is due mostly to carbonaceous matter. Breaks with a pronounced conchoidal fracture yielding sharp edges.
> Chert. A flint-like variety with gray color.
> Agate. A banded chalcedony.

Chalcedony, like quartz, does not alter in weathering but it is slightly more soluble than quartz in ground water.

Chert and flint are very common and abundant constituents of many limestone soils. Chalcedony pebbles, especially jasper, are common in some gravels.

Hematite

Fe_2O_3. Ferric oxide. Fe 70 per cent, O 30 per cent. Part of the iron may be replaced by magnesium or titanium.

Color black, steel gray, or red. Streak red. Dull to shiny metallic. Brittle. No true cleavage. Fracture irregular to

subconchoidal.   Hardness 5.5 to 6.5.   Specific gravity 4.9 to 5.3.   Occurs in a great variety of forms.

Fusible with difficulty.   Becomes magnetic on charcoal in reducing flame.   Soluble in hot HCl.

One of the most common of the decomposition reactions of hematite is by hydration to limonite according to the formula:

$$2Fe_2O_3 + 3H_2O = 2Fe_2O_3{\cdot}3H_2O.$$
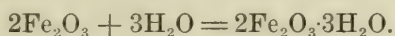
By reduction hematite may alter to siderite or magnetite as a soil reaction; however, this change takes place only in the presence of such strong reducing material as an abundance of organic matter.   Turgite and goethite are also common products of hematite alteration.

Hematite is one of the most widespread of soil minerals.   It occurs in distinct grains, scales, included matter in the pebbles of gravel, coatings on sand grains, as incrustations, pulverulent matter disseminated through clay, or as the cementing material in ''hardpan''.   In the latter condition it is very detrimental. It is, with turgite, the chief coloring material in the red soils.

Rutile

Titanium dioxide, TiO_2.

The mineral is brown or reddish brown in color, very hard, infusible and insoluble.

Rutile is fairly common in minute amounts.   In some soils it occurs as small, inert, sparsely disseminated grains.

Pyrolusite

MnO_2.   Mn 63.2 per cent.

A black, fibrous, acicular or columnar mineral.   Very soft. Specific gravity 4.7 to 4.9.   Lustre dull metallic.

Manganese reaction with borax bead.   Infusible.   Soluble in HCl with evolution of chlorine.

The mineral is found in clays and in nodular or concretionary masses in clay soils.   It is more abundant in moist than in dry soils.   The value of manganese in the soil is little understood but there is evidence that its presence in small amounts is beneficial to many crops.

4. HYDROXIDES AND HYDROUS OXIDES

Opal.

$SiO_2 \cdot nH_2O$.   The water content varies from 3 per cent to 15 per cent.

Opal is always amorphous.   No cleavage.   Conchoidal fracture.   Hard and very brittle.   Greasy or waxy lustre.   Translucent and often with opalescence.   Colorless or any color.

In soils of occasional occurrence as pebbles or grains from the decomposition of lavas, sinters, diatom and radiolarian deposits, or the disintegration of petrified wood.

Turgite (Hydrohematite, Red ochre)

$2Fe_2O_3 \cdot H_2O$.   Contains 66.2 per cent iron.

Turgite occurs in red, earthy or clayey masses, or in brownish amorphous masses and crusts resembling limonite from which it may be distinguished by its red streak.

Turgite is intermediate in its composition between hematite and limonite and is often formed as an intermediate product in the change from hematite to limonite or from limonite to hematite.

It is very common as red coloring matter in the soil and as a constituent of "hardpan".

Goethite

$FeO(OH)$ containing 62.9 per cent iron and generally a little manganese as impurity.

The mineral is yellow, red, or brown in color.   It occurs in scaly or fibrous masses or crusts, in crystals, or in massive form.

It is found in soils with hematite, turgite, and limonite from any of which it may have formed or into any of which it may alter.   It also occurs as inclusions in other soil minerals.   During dry seasons it may partly dehydrate to hematite or turgite.

Limonite

Hydrated ferric oxide, $2Fe_2O_3 \cdot 3H_2O$.   Contains 59.8 per cent iron.   Considerable amounts of manganese and phosphorus are often contained in the mineral as impurity.

Color variable, from nearly black through brown to various shades of yellow. Streak yellow or yellowish brown. Lustre silky, dull or shiny metallic, or earthy. Brittle or friable. No cleavage, irregular fracture. Hardness 5 to 5.5. Specific gravity 3.6 to 4.

Fuses with difficulty and yields a metallic residue with the reducing flame or on charcoal. Borax bead reactions for iron. Yields water in a closed tube. Soluble in HCl.

Limonite may alter by reduction, through the agencies of carbon dioxide and decaying organic matter, to siderite. By dehydration it alters to hematite. Common changes are also to turgite and goethite.

Limonite is one of the most common soil constituents. When in finely powdered form, or as staining material in other minerals, it is the chief coloring material of yellow clays and soils. In larger grains, not reduced to the size of particles of mineral streak, it is the most abundant and widespread of brown coloring pigments. It sometimes occurs as cementing material forming "hardpan" but it is less common than turgite in this form. Through dehydration it furnishes a source of soil hematite, and through reduction and carbonation it gives rise to soluble iron. The reduction of ferric oxides and ferric hydroxide is a particularly pronounced phenomenon of poorly drained soils.

Psilomelane

$4Mn(Ba, K_2)O_2 \cdot H_2O$. The mineral is not constant in its composition and the MnO content varies from 70 per cent to 90 per cent. H_2O 3 per cent to 9 per cent. Barium and potassium are usually present.

Properties are similar to pyrolusite, but it differs from that mineral in greater hardness and in yielding water in a closed tube. Psilomelane is always amorphous.

The occurrence is the same as for pyrolusite, with which it is almost always associated in the soil.

Brucite

$Mg(OH)_2$. Often contains ferric and manganese hydroxide impurities.

A white, bluish, or greenish, sectile mineral of fibrous, foliated, or crystalline structure. Lustre pearly, silky, or waxy.

Its most frequent associates are dolomite, magnesite, and serpentine.

Diaspore

Hydrous oxide of aluminium, $AlO(OH)$.

A hard, very brittle mineral occurring in foliated or banded condition. Varying color. Streak white. When pure it is transparent and white or pinkish. Infusible. Decrepitates. Insoluble. Yields water in closed tube. Blue color with cobalt nitrate.

Diaspore is a common constituent of bauxite and laterite soils and by the addition of one molecule of water may alter to gibbsite. In hot dry regions if present it may be partially dehydrated.

Gibbsite (Hydrargillite)

Aluminium hydroxide, $Al(OH)_3$. Traces of phosphoric acid are frequently reported in the analyses. The pure mineral is rarely found.

The mineral when pure is white but in nature occurs in all colors. Hardness 2.5 to 3.5. Generally fibrous in structure. Flexible and sectile.

Gibbsite may be formed by the extreme weathering of aluminous rocks, and it thus forms an important constituent of the soils of moist tropical and subtropical countries. It is absent from the soils of dry regions and becomes less abundant as cooler climates are approached. The well-known bauxite deposits and aggregates of bauxite soils appear to be mixtures of gibbsite, diaspore, and free quartz. Laterite and laterite soil aggregates, so abundant in the tropics, appear to be composed of mixtures of gibbsite, diaspore, limonite, and sometimes quartz.

5. SILICATES

Muscovite (Isinglass, White mica, Potash mica)

$H_2KAl_3(SiO_4)_3$. K_2O 9.2 per cent. An acid hydrogen-potassium-aluminium orthosilicate with small amounts of sodium,

ferric iron, or magnesium by replacement. Inclusions of ferro-magnesium silicates frequently occur. In composition this is the simplest mica.

Colorless when pure, but when impure may show any pale color. Streak white and difficult to obtain. Lustre pearly, or sometimes silky on edges, pearly or vitreous on cleavage planes and very bright. Elastic. Cleavage perfect in one direction into thin sheets. Micaceous structure. Hardness 2 to 2.5. Specific gravity 2.7 to 3.

Fuses on thin edges only, forming a yellowish glass. Yields a little water in closed tube. Insoluble in HCl and H_2SO_4.

Muscovite splits and is broken up by the physical agencies of weathering into small flakes. Chemically it is one of the most stable of the common minerals, decomposition taking place only in the later stages of weathering. In the only recognized changes by weathering the muscovite may release its potassium as a carbonate by the substitution of bases when in contact with ground water containing the carbonates of sodium, calcium, or magnesium. The resulting end-product will be talc with libera-tion of gibbsite, or some form of vermiculite, depending upon the ground water conditions. Muscovite may also alter directly to clay by the complete substitution of hydrogen for the base through the agency of water containing carbon dioxide. This change is accompanied by loss of elasticity and transparency. The minute scales of muscovite found in clays formed by the decomposition of feldspar may sometimes be considered as inter-mediate products between the feldspar and kaolinite.

Muscovite is one of the commonest and best known minerals and is a very common ingredient of sandy soils in which it occurs as sparkling flakes, generally of minute size. It is a common mineral of clay soils also, and when present in these is of much value because of its causing the soil to have a more open texture and facilitating tillage. The potassium, on account of the high stability of the mineral, is liberated very slowly and thus forms a reserve supply.

Biotite (Black mica)

Approximately $(HK)_2(Mg, Fe)_2Al_2(SiO_4)_3$. An acid iron-magnesium orthosilicate containing potassium and aluminium.

The iron may be either ferrous or ferric or partly each. Traces of barium, chromium, manganese, and titanium may appear in the analysis. Small crystals of apatite, zirconium silicate, titanium oxide, and the iron oxides are often included within the mica sheets.

Color black, dark brown, brown, or occasionally greenish, depending on variation in composition and the stage of weathering. Streak white or gray and difficult to obtain. Lustre pearly, vitreous, or submetallic in kind and varying in degree from bright when fresh to dull when weathered. Elastic or flexible when fresh, becoming brittle or tough when weathered. Cleavage perfect in one direction. Hardness 2.5 to 3. Specific gravity 2.7 to 3.1. Micaceous in structure.

Whitens and fuses on thin edges. Yields a little water in closed tube on intense heating. Decomposed with boiling H_2SO_4 with the separation of silica scales. By careful treatment will usually give iron reactions with borax bead or a magnetic globule by fusion with soda on charcoal.

The first stage of weathering is usually evidenced by a loss of elasticity, decrease in brilliancy of lustre, and change in color to rusty, greenish, or yellowish brown. Upon further alteration the potassium, and then the iron, is separated from the compound, their places being taken by hydrogen, in which condition the mineral loses its mica cleavage and becomes more scaly. In this form it may be known as hydromica or as vermiculite. The final stage of decomposition is to chlorite by the further addition of hydrogen, the complete loss of the alkali, and the change of most of the remaining ferrous to ferric iron. Chlorite thus produced is accompanied by quartz, iron and magnesium carbonates, iron oxide, and dissolved potassium. A less common alteration is to serpentine with accompanying kaolinite.

Biotite, because of its lower stability, is less common than muscovite in soils and when present generally is weathered, exhibiting a greenish color and a dull or resinous lustre. The potash is less in amount than in muscovite but more readily becomes available in soluble form.

Phlogopite (Amber mica)

A magnesium mica rich in potassium and containing small varying amounts of hydrogen and fluorine.

Intermediate in color between biotite and muscovite. Easily decomposed by H_2SO_4 with separation of silica scales. Usually gives reactions for both iron and fluorine.

The mica is less abundant than biotite or muscovite. In sediments and soils it is not common, being usually removed by decomposition in weathering. The mineral alters readily by simple hydration releasing its potassium as an hydroxide, the residual mass constituting a vermiculite mineral. In some cases hydration of both the potassium and aluminium has been noted leaving talc as an end-product.

Orthoclase

$KAlSi_3O_8$. Orthoclase is potassium-aluminium trisilicate, a salt of the hypothetical acid $H_4Si_3O_8$. When pure the mineral contains 64.7 per cent SiO_2 and 16.9 per cent K_2O. Impurities in the form of sodium-aluminium trisilicate and ferric oxide are frequently present.

Colorless when pure but usually gray, flesh color, yellow, red (due to finely disseminated ferric oxide), or pink. Green color due to ferrous silicate may occur. Streak white. Lustre vitreous or pearly, bright on fresh surfaces but becoming dull on weathering. Brittle. Cleavage perfect in two planes at right angles to each other (Fig. 1). Fracture conchoidal or uneven. Hardness 6 which may be reduced by weathering. Specific gravity 2.56.

Fusible on sharp points. May color the flame violet. Insoluble in HCl, HNO_3 and H_2SO_4.

Orthoclase is very easily alterable, yielding to hydration alone, hydration and carbonation, soil acids, and sulphides. The decomposition is much aided by the cleavage which renders the mineral liable to disintegration and to the action of solutions along the cleavage planes. The most important alteration is by hydration and carbonation to kaolinite, quartz, and soluble potassium according to the following equation:

$$2KAlSi_3O_8 + 2H_2O + CO_2 = H_4Al_2Si_2O_9 + SiO_2 + K_2CO_3.$$
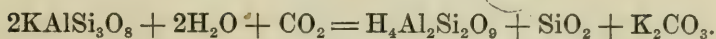
Orthoclase may also alter by hydration without complete removal of the potassium into the sericite variety of muscovite,

although this reaction is not a very common weathering process.

Orthoclase is one of the most abundant and important minerals both in the rocks and in the soils. It is the largest primary source of soluble potash, and together with plagioclase forms the chief source of the kaolinite of clays. The potassium liberated by orthoclase decomposition is supposed to change place largely with the soda of zeolites, where the latter are present, and thus become fixed in the soil. Minute fragments of orthoclase are present in most soils where they are slowly liberating potassium carbonate. Orthoclase has been pulverized and used as a fertilizer but without much success because the liberation of the potassium is too slow.

Microcline

Chemical composition similar to orthoclase.

It is somewhat more resistant to weathering than orthoclase but produces the same end-products.

Plagioclase (Soda-lime feldspar)

The plagioclase feldspars constitute a series of varieties consisting of Albite, $NaAlSi_3O_8$; Anorthite, $CaAl_2(SiO_4)_2$; and isomorphous mixtures of the two. The most important of these mixtures in soil formation are Oligoclase, in which the sodium-aluminium silicate is in excess of the calcium, and Labradorite, in which the sodium and calcium are about evenly divided or the calcium is somewhat in excess. The plagioclases vary from 0 per cent to 9.4 per cent sodium and 0 per cent to 20.1 per cent calcium. The most common impurities are titanium and iron, and less commonly, magnesium.

Streak white. Lustre vitreous on edges and vitreous or pearly on cleavage surfaces. Brittle. Cleavage well developed in two directions nearly at right angles. Fracture uneven or conchoidal across cleavage surfaces. Hardness 6 which may be reduced to 5 or even 4 by weathering. Specific gravity 2.5 to 2.8. Structure bladed, laminated, or striated crystals.

Fuses with difficulty. Not much affected by acids.

> Albite. White or light gray in color. Cleavage surfaces not perfect. Less distinctly bladed than other varieties usually. Insoluble in HCl.

Oligoclase.   White, gray, or rarely greenish or reddish. Often finely striated.   Insoluble in HCl.

Labradorite.   Dark or bluish gray cleavable masses, often with beautiful blue, green or red iridescence.   Broadly striated.   Slightly soluble in HCl.

Anorthite. A rare mineral. Very broadly striated. Soluble in HCl.

Plagioclase is easily alterable and changes in many ways not fully understood.   The best defined weathering processes are described below.   The decomposition of Albite is exactly parallel to that of orthoclase into kaolinite and insoluble quartz with the substitution of soluble sodium carbonate for soluble potassium carbonate.   The equation is given:

$$2NaAlSi_3O_8 + 2H_2O + CO_2 = H_4Al_2Si_2O_9 + 4\overset{quartz}{SiO_2} + Na_2CO_3.$$
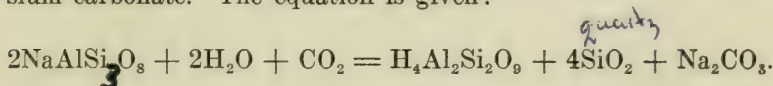
Oligoclase of the proportion of: $4NaAlSi_3O_8 + CaAl_2Si_3O_8$

will decompose to a calcareous clay with soluble sodium carbonate and insoluble quartz as follows:

$$Oligoclase + 6H_2O + 3CO_2 = 3H_4Al_2Si_2O_9 + CaCO_3 + 2Na_2CO_3 + 8SiO_2.$$
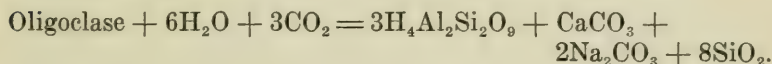
Anorthite by hydration and carbonation alters to calcareous clay as follows:

$$CaAl_2Si_2O_8 + 2H_2O + CO_2 = H_2Al_2Si_2O_9 + CaCO_3.$$
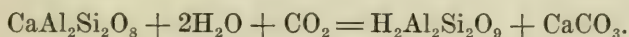
Labradorite may alter by hydration and carbonation to a clay richer in calcium and poorer in silica and sodium than oligoclase. Zeolites may also form later to be changed to kaolin.

Plagioclase, together with orthoclase, comprises the feldspar group, by far the most abundant and widespread minerals.   Feldspar is the chief source of clay, and the decomposition of feldspar by hydration and carbonation is chemically the most important mineral alteration in soil production.

Nephelite (Nepheline, Elaeolite)

$NaAlSiO_4$, with from one-fifth to one-fourth of the sodium replaced by potassium.

White, gray, or reddish. Cleavage not very distinct. Lustre greasy. Hardness 6.

The mineral decomposes readily giving rise to zeolites and ultimately to clay with the liberation of silica. The soil resulting from nephelite decomposition is generally rich and fertile.

Hornblende

$$mCa(Mg, Fe)_3(SiO_3)_4 + n(Al, Fe)\ (F, OH)SiO_3 +$$
$$Na_3Al_2(SiO_3)_4.$$
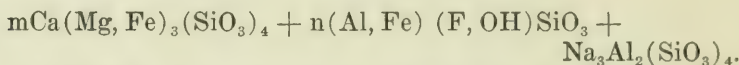
Hornblende is a mixture of metasilicate of calcium, magnesium, and ferrous iron with varying amounts of metasilicate of aluminium, sodium, and ferric iron with fluorine and hydroxyl. The exact structural constitution of the molecule is but little understood. Apatite and magnetite may occur as inclusions and in metamorphic hornblende rutile may also occur.

Color dark green or black, occasionally dark brown. Streak gray or greenish. Lustre vitreous, bright on cleavage surfaces, dull on edges or in weathered specimens. Brittle. Cleavage perfect in two directions. Fracture uneven. Hardness 5 to 6. Specific gravity 3 to 3.2. Columnar or bladed, less often fibrous.

Fuses to a black or dark colored glass which may be magnetic. Insoluble in acids.

Hornblende decomposes readily and, although hard, it also disintegrates rapidly under mechanical wear because of its easy cleavage. The first step in the ordinary decomposition is the oxidation of the ferrous to ferric iron with its hydration and separation as limonite. The calcium, magnesium, and sodium are easily carbonated and separated from the aluminium and silicon in the form of carbonates leaving behind hydrated silicate of aluminium in the form of clay. The decomposition may also take place directly to chlorite accompanied by quartz, epidote, calcite, and iron oxide, thence ultimately to clay.

Hornblende together with tremolite, actinolite, and a few varieties of little consequence to soil men, compose the highly important amphibole group. The minerals are of great im-

portance in the liberation of iron oxides, iron, magnesium and calcium carbonates, and to a less extent clay to the soil.

Tremolite

$CaMg_3(SiO_3)_4$.
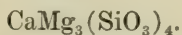
An amphibole closely related to hornblende. White or gray in color. Rarely in soils. May alter to talc.

Actinolite

$Ca(Mg, Fe)_3(SiO_3)_4$.
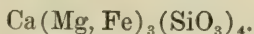
Bright to dark green. Generally columnar. (Fig. 4.) Rare in soils. Alters slowly to serpentine and associated calcite.

Pyroxene (Augite)

$Ca(Mg, Fe)(FeAl)(SiO_3)_2 + CaMgFe(SiO_3)_3 + AlFeSiO_6$.
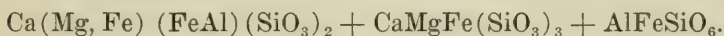
The pyroxenes constitute an important series of minerals which are represented by metasilicates of calcium, magnesium, ferrous and ferric iron. By the addition of aluminium and sodium varieties are obtained which are calcium-aluminium-sodium-ferric metasilicates. By the decrease of aluminium and magnesium, ferric or calcium, or mixed calcium and ferric metasilicates are reached at the other end of the series. In their relation to soil formation they may be regarded as forming two series, one aluminous and the other non-aluminous. The presence of the SiO_6 radical is hypothetical. TiO_2 is sometimes present.

Color dark green, brown or black. Streak white, gray or greenish. Dull vitreous lustre. Brittle. Cleavage in two directions nearly at right angles. Fracture uneven. Hardness 5 to 6. Specific gravity 3.2 to 3.6. Tabular, columnar or bladed.

Fuses readily to a dark glass which is sometimes magnetic. Insoluble, or but slightly soluble, in acids.

The most common alteration of pyroxene is by hydration to serpentine and chlorite with the separation of calcite and silica. If much aluminium is present in the original pyroxene accompanying kaolinite may develop. If the iron content is high limonite and siderite may be liberated with the change to chlorite. Another method of decomposition is to chlorite with the calcium and surplus silicon forming basic calcium ortho-

silicate in the form of epidote. Another common alteration is
to talc. A less common alteration is to epidote with the libera-
tion of magnesium salts. Another decomposition product of
some importance is celadonite, which see under glauconite.

Pyroxene is a fairly common mineral of gravelly, sandy and
loamy soils in regions of basic igneous rock. On decomposition
soluble iron and calcium compounds and iron stains are liberated
to the soil. Insoluble, hydrous, scaly silicates are formed as a
residue and these have a marked effect on the soil texture. From
the aluminous varieties clay is formed in considerable amounts.

Enstatite and Hypersthene

These two minerals belong to the pyroxene group. They
are metasilicates of iron and magnesium, the enstatite containing
less than 10 per cent ferrous iron and the hypersthene more than
10 per cent. On thorough decomposition they yield to the soil
quartz, limonite, and calcium and magnesium carbonates.

Epidote

$Ca_2(Al, Fe)_3(OH)(SiO_4)_3$.
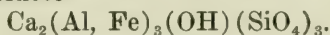
A basic orthosilicate of calcium and aluminium with varying
replacement of the aluminium by ferric iron.

Color usually green but may be yellowish, brownish, or nearly
black, depending on the iron content. Streak white or gray.
Vitreous. Brittle. Cleavage distinct in one direction and often
imperfect in a second direction. Fracture uneven. Hardness
6 to 7. Specific gravity 3.3 to 3.5. Most frequently granular,
also massive or columnar, rarely fibrous.

Fuses with intumescence, the resulting globule being mag-
netic. Slightly soluble in HCl, the degree of solubility depend-
ing on the iron content. After fusion will yield gelatinous silica
with HCl.

Epidote is very resistant to chemical weathering. It breaks
up slowly in soils to calcite, quartz, kaolinite, and iron oxide.
It is more abundant in maturely than immaturely weathered soils.

Garnet

The garnets form an isomorphous series of orthosilicates with
the general formula $R''_3R'''_2(SiO_4)_3$, where R'' is Ca, Mg, Fe'',
Mn and R''' is Al, Fe''' and Cr.

Color varies greatly due to the differences in chemical composition. Lustre vitreous or resinous. Hardness 6 to 8. Cleavage very perfect if it is at all developed.

Because of its great hardness and the slight decomposibility of the varieties low in ferrous iron and calcium these are often found as undecomposed grains as constituents of sands. The varieties of higher ferrous iron, magnesium and calcium content alter with the production of chlorite and talc or serpentine, ferric oxide and clay.

Olivine (Chrysolite, Peridot)

$(Mg, Fe)_2SiO_4$. A magnesium-iron orthosilicate, the ratio of the magnesium to the iron varying widely. Small amounts of calcium and manganese often appear. The SiO_2 may be replaced by TiO_2 up to about 5 per cent.

Color some shade of green, rarely reddish brown if much oxidized iron is present. Streak white. Vitreous. Brittle. Cleavage not easily distinguished. Fracture conchoidal. Hardness 5 to 6. Specific gravity 3.2 to 3.5. Granular.

Infusible unless the iron content is high in which case it fuses to a magnetic mass. Gelatinizes with HCl.

Olivine decomposes with great facility. The most important alteration is to serpentine. This change is accomplished by means of simple hydration and carbonation as follows:

$$2(Mg, Fe)_2SiO_4 + 2H_2O + CO_2 = H_4Mg_3Si_2O_9 + (Mg, Fe)CO_3.$$
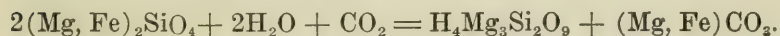
The final end-product may be an aggregation of iron hydroxides, quartz, and magnesium carbonate.

Olivine by its ready alteration in rock masses is of great importance in promoting disintegration of the rock to soil. In the soil itself the mineral is generally absent but is represented by serpentine or magnesium carbonate, iron hydroxide, and quartz.

Zircon

$ZrSiO_4$. Zirconium orthosilicate.

Usually some shade of yellow or brown. Crystalline. Very hard.

The mineral is very resistant and where present in soil usually occurs as inert, disseminated grains.

Kaolinite (Kaolin)

$H_4Al_2Si_2O_9$. An acid aluminium silicate containing, when pure, about 46 per cent SiO_2 and 40 per cent Al_2O_3 with 14 per cent H_2O. It may be regarded as alumino-disilicic acid.

White or gray but when impure may assume any color. Streak white or yellowish. Friable in masses. Hardness 1 to 2.5 in mass. Specific gravity 2.6. Earthy, scaly, mealy or powdery in mass (Fig. 2).

Infusible. Becomes blue on ignition with cobalt nitrate. Insoluble in HCl and HNO_3 but soluble in H_2SO_4.

Kaolinite is a very stable compound under soil conditions and through weathering forms and becomes concentrated in large amounts. Alteration, by the breaking off of the silica, to the aluminium hydroxides gibbsite and diaspore has been noted in the last stages of weathering under favorable conditions.

Kaolinite is the best known, the most common, and the only well-characterized hydrous silicate of aluminium. It is the most characteristic mineral of clay but clays are composed of varying percentages of quartz, carbonates, iron oxide and hydroxide, organic materials, colloidal gels and vaguely defined aluminous compounds probably of unstable composition mixed with it.

Serpentine

$H_4Mg_3Si_2O_9$. Magnesium silicate with part of the magnesium usually replaced by ferrous iron. SiO_2 44.1 per cent, MgO 43 per cent, H_2O 12.9 per cent.

Usually varying shades of green, often mottled. Yellow, brown or red colors may occur. Streak white. Lustre greasy, silky or waxy. Brittle, or flexible in fibrous specimens. Cleavage not determinable by inspection. Fracture conchoidal or splintery. Hardness 2.5 to 4. Specific gravity 2.5 to 2.65. Granular, compact, foliated, fibrous or amorphous (Fig. 3).

Fuses on thin edges. Yields water in closed tube. Becomes pink on ignition with cobalt nitrate. Decomposed by H_2SO_4 and dissolved by HCl leaving a residue.

By carbonation serpentine slowly breaks down into magnesium carbonate and crystalline or amorphous silica.

Serpentine is not of value to soils either by liberation of plant foods or by improvement of physical conditions. Soils formed largely from serpentine rock are usually infertile.

Talc (Steatite, Soapstone)

Talc is an acid metasilicate of magnesium, $H_2Mg_3(SiO_3)_4$.

A soft, soapy mineral occurring in foliated, fibrous, scaly or massive form.

In soils it forms an inert, and usually very minor, constituent.

Zeolite

The zeolites form a large group of secondary metasilicates of aluminium, calcium, sodium, and potassium, with weakly combined water. Three of the group, *Analcite* (sodium-aluminium), *Apophyllite* (potassium-calcium), and *Stilbite* (sodium-calcium-aluminium) zeolite are important as soil constituents.

The minerals are light colored. Hardness 3 to 3.5. Specific gravity 2 to 2.5. Easily fusible. Decomposed by HCl.

Much interest is attached to the problem of the presence and importance of zeolites in the soil. Their presence in any appreciable amount in crystalline form is rarely observed but their presence in a finely pulverized condition or in colloidal or gelatinous form is implied by soil chemical reactions. The part believed by many students to be played by them is the taking up of the stronger bases, sodium and potassium from solutions, liberating in their places their weaker bases. They may thus become important conservers of soil potassium which is then slowly liberated by their decomposition. In many regions of high temperature and low humidity partial dehydration may occur. By separation of their bases kaolinite is produced.

Burgess and McGeorge have recently shown at Tucson, Arizona that sodium zeolite may be formed in the cold by reaction between sodium aluminate and sodium silicate, both of which occur in "black alkali" soils.

Chlorite

$H_8(MgFe)_5Al_2(SiO_6)_3$. (Generalized formula.) Chlorite is the name of a group of closely related, variable species the distinction between which is neither easy nor practical for soil work. The variety formulae vary considerably but approximate the generalized formula. The chlorites are acid silicates of aluminium, magnesium, and ferrous iron with varying amounts of

silicon and chemically combined water. The minerals may be considered as mixtures of the salts of two silicate radicals, Si_2O_9 and SiO_9. Inclusions of iron oxide and sulphide are common.

Color green. Streak pale green to white if finely ground. Pearly to submetallic. Brittle, flexible, tough, or slightly sectile. Cleavage perfect in one direction. Hardness 1.5 to 2.5. Specific gravity 2.65 to 2.95. Scaly or granular or in the soil in disseminated flakes.

Fuses, the difficulty depending on the variety. At high temperatures yields water in a closed tube. Decomposed by H_2SO_4. Most varieties decomposed by HCl with separation of silica.

Important varieties are:

> Clinochlore. $H_8(Mg, Fe)_5Al_2Si_3O_{18}$. Flexible. Harder than 2.
>
> Prochlorite. $H_{40}(Mg, Fe)_{13}Al_{14}Si_{13}O_{20}$. Slightly sectile. Softer than 2.

The chlorites themselves are secondary minerals and composed of molecules highly stable under atmospheric conditions. Definite information concerning their decomposition by weathering is lacking except that their end-products may be mixtures of iron oxide, iron hydroxide, iron and magnesium carbonates, silica, and clay

Chlorite is largely an inert soil constituent contributing little of value for plant food. It may render the texture of very heavy soils more open, if not present in too great amounts, but where abundant it tends to produce scalyness or stringyness.

Saussurite

The name saussurite was first applied to a mineral mass supposed to represent a distinct species, but since found to be a variable mixture of hydrous aluminium silicates of calcium and sodium, together with quartz and sometimes feldspar.

Vermiculite

Vermiculite is a name given to a series of indefinite mineral compounds intermediate in chemical character and physical prop-

erties between mica and chlorite. The vermiculites are all secondary products.

Tourmaline

A complex silicate of aluminium and boron containing iron, magnesium, and alkali metals. The mineral is very variable in composition, color, structure, and specific gravity.

As a soil constituent it occurs in small amounts as an inert ingredient in soils produced by very mature weathering, especially if transportation is involved. In such soils it has been concentrated in noticeable amounts by the weathering out of the other original silicates, it being among the most resistant to weathering processes.

Glauconite (Greensand)

Glauconite is a hydrated aluminium silicate of iron and potassium generally containing small, varying amounts of calcium, magnesium, and sodium. The potash content reaches a maximum of 7 per cent and is readily available.

Glauconite is a fairly common constituent of sandstones throughout the Atlantic and Gulf Coastal Plains. In southern New Jersey it has been quarried and marketed as a potash fertilizer. It is frequently present in soils in all gradations from freshness to complete alteration into limonite and clay. Clarke (U. S. G. S. Bull. 330, P. 494), states that glauconite formation may be ''one of the modes by which potassium is withdrawn from its solution in ground water.''

Celadonite, which is a decomposition product of pyroxene, may be identical with glauconite.

6. CARBONATES

Calcite

$CaCO_3$. Ca 40 per cent, CO_3 60 per cent. Iron, magnesium and manganese are the most frequently found impurities.

Usually colorless, white, or yellow, but may occur in any color. Streak white. Lustre vitreous to dull, in rhombs it may approach pearly. Brittle. Cleavage perfect in three directions into rhombs. Hardness 3. Specific gravity 2.7.

Infusible. Easily soluble in cold dilute HCl with effervescence. In closed tube whitens and evolves CO_2.

Calcite readily changes in rock decomposition to the highly soluble bicarbonate of calcium. The reaction is as follows:

$$CaCO_3 + H_2O + CO_2 = CaH_2(CO_3)_2.$$

Calcite is one of the most abundant and widespread of soil minerals and with aragonite and gypsum is the only known common *direct* source of soluble calcium. Calcium is an essential plant food and calcite, either as an original mineral of the soil or as a secondary mineral formed through the decomposition of silicates, or as a dissolved salt of soil water, is an essential constituent of all fertile soils. Calcite generally accumulates in much greater quantities in the subsoil than in the soil. In humid regions it may be carried downward in solution and redeposited in the subsoil as a cementing material producing calcareous ''hardpan''. The effect of $CaCO_3$ in holding the soil floccules and producing a flocculated structure is an important factor in rendering tillage easy. Calcite in the form of limestone is added to the soil as a corrective for ''sourness''.

Aragonite

$CaCO_3$, chemically the same as calcite but differing from it physically.

Hardness 3.5 to 4. Specific gravity 2.9. Decrepitates and falls to pieces in a closed tube.

It alters the same as calcite but is less stable.

Dolomite

$CaMg(CO_3)_2$. Normally calcium 21.6 per cent and magnesium 13.1 per cent but this may vary by replacement. Dolomite is a double salt and not an isomorphous mixture of calcium and magnesium carbonates. Small amounts of iron and manganese are often present.

Color variable but the most common colors are white, gray, pink, or blue. Streak white. Vitreous or pearly. Brittle. Perfect cleavage like calcite. Hardness 3.5 to 4. Specific gravity 2.8.

Effervesces but slightly with cold dilute HCl but vigorously with warm or concentrated HCl. Infusible. Becomes pink with cobalt nitrate. Yellowish red flame color on platinum wire.

Although magnesium is an essential plant food soils containing a large amount of magnesium salts in proportion to the calcium salts are notably sterile. Soils containing small amounts of dolomite may be fertile but if the mineral forms a large percentage of the soil, or exceeds the calcium carbonate content, the soil rapidly becomes barren.

Magnesite

$MgCO_3$. White in color when pure. Hardness about 4.5. Cleavage as in calcite. Dull to vitreous lustre. Soluble with effervescence in hot HCl.

The mineral is far less common than dolomite.

Trona (Black alkali)

$Na_3H(CO_3)_3 \cdot 2H_2O$ or $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$. An excess of CO_2 over the normal carbonate is always present.

White, gray or yellowish crystalline material occurring in crusts or scattered crystals. Hardness 2.5 to 3. Lustre vitreous. Alkaline taste. Soluble in water and with effervescence in HCl. Easily fusible.

Trona is formed by precipitation from evaporating lake and enclosed sea waters. Owing to its method of formation and its high solubility it is confined to dry areas. It does not alter by weathering in the absence of atmospheric moisture.

Trona is a highly injurious soil mineral. One harmful effect of the mineral is the deflocculation of the clay particles rendering tillage difficult and the soil nearly impervious to water. Another injurious effect is produced by its solution of soil humus precipitating it in black spots, from the presence of which the term "black alkali" is derived. Reactions with calicum sulphate will replace the carbonate with the less objectionable sodium sulphate.

Siderite

$FeCO_3$, ferrous carbonate. Fe 48.3 per cent. Calcium, magnesium, and manganese may be present in small amounts as replacing metals. Included carbonaceous matter is common.

Gray, brown of varying shades, or nearly black from carbonaceous matter. Streak white. Vitreous. Brittle. Cleavage rhombohedral. Hardness 3.5 to 4. Specific gravity 3.8. In the soil in masses, grains, crusts and coating material.

Soluble in acids with effervescence in hot HCl. Tests for ferrous iron. Fuses with difficulty before the blowpipe becoming black and magnetic.

In soil siderite by oxidation may pass into hematite, by oxidation and hydration into limonite or turgite, or by hydration and carbonation into soluble ferrous bicarbonate.

The importance of siderite as a soil constituent lies chiefly in it as a source of soluble iron and of iron rust, or ferric hydroxide. It is also an important factor in the formation of many "hardpans".

7. SULPHATES

Gypsum

$CaSO_4 \cdot 2H_2O$. Hydrous sulphate of calcium.

Colorless when pure, but may be any color. Lustre vitreous, silky, or pearly. Streak white. Cleavage perfect in one direction and imperfect in two directions. Hardness 2. Specific gravity 2.3. Brittle except when foliated. Folia flexible. Granular, compact, earthy, fibrous, or drusy masses.

Easily fusible to a white globule coloring the flame yellowish-red. Yields water in a closed tube. Easily soluble in dilute HCl.

Gypsum may interreact in the soil in so many different ways that any generalized statements concerning its alterations must be accepted with caution and subject to modification. In hot, dry climates it may be dehydrated to anhydrite. With carbonates it may interreact giving $CaCO_3$ and sulphates of sodium, potassium, and iron, or sulphide of iron.

Gypsum in many parts of the United States is a common mineral. It is extensively used in the manufacture of fertilizer. Gypsum is especially effective as a corrective for "black alkali" reacting with which it produces $CaCO_3$ and Na_2CO_3. The growth of legumes is promoted by its presence in the soil and the mineral acts as a valuable stimulator of nitrification.

Anhydrite

$CaSO_4$. Anhydrous calcium sulphate is of less common occurrence than gypsum from which it may be distinguished by its slight solubility in HCl. It is also somewhat harder and heavier than gypsum.

By absorption of water anhydrite may alter to gypsum.

Mirabilite (Glauber's salt)

$Na_2SO_4 \cdot 10H_2O$.
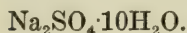
The mineral occurs as powder or in crusts in soils of arid or semi-arid regions where it is brought to the surface and deposited by rising water.

The mineral is whitish, very soft, but little heavier than water, easily soluble in water, and with a very bitter, salty taste. It yields abundant water in a closed tube and gives reactions for sulphur.

Mirabilite is the chief constituent of "white alkali" and while injurious to most plant growth is far less so than trona or "black alkali". By treatment with gypsum the exceedingly harmful trona is converted into the far less harmful mirabilite. Mirabilite is also much less harmful in appreciable quantities than sodium chloride.

Epsomite

$MgSO_4 \cdot 7H_2O$.
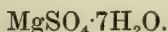
Color and streak white. Soft. Specific gravity 1.7. Soluble in water. Yields water in a closed tube. Intensely bitter taste.

It occurs in solution in small amounts in mineral waters and as white fibrous or earthy crusts. In arid regions it is formed at the surface by deposit from rising waters which evaporate on reaching the surface. It is also formed by the action of sulphuric acid from decomposing sulphides or magnesium silicates. In large deposits it is formed by evaporation of the waters of inland seas.

Epsomite is an undesirable soil constituent, being somewhat more injurious than mirabilite.

Kainite

$MgSO_4 \cdot KCl \cdot 3H_2O$. Contains 15.7 per cent K and 21.7 per cent H_2O.

Kainite has been used as a mineral fertilizer for soil deficient in potassium. The large chlorine content and an admixture of sodium chloride impurity render the mineral useless however in arid regions and harmful to crops injured by a small amount of chlorine.

Copperas (Melanterite)

$FeSO_4 \cdot 7H_2O$.

A pale green mineral sometimes occurring in crusts or as pulverulent material, but generally passing off in solution as rapidly as formed. Easily fusible. Yields water in a closed tube. On charcoal yields a magnetic residue. Hardness 2. Specific gravity 1.9. Soluble in water.

Copperas forms readily by the oxidation of pyrite or marcasite in moist air. Its high solubility prevents its accumulation in the soil except in some dry regions. When present it is highly injurious in solution in the ground water.

8. PHOSPHATES

Apatite

$Ca_5(Cl, F)(PO_4)_3$. $Ca_3(PO_4)_2$ 92.1 per cent. The mineral is an isomorphous mixture of calcium phosphate, calcium fluor-phosphate, and calcium chlor-phosphate.

Color generally red or green but occasionally other colors. Streak white. Brittle. Vitreous. Cleavage imperfect. Hardness 5. Specific gravity 3.2.

Fusible on thin edges. Soluble in HCl and with effervescence in hot HNO_3. On heating a yellow precipitate is formed from the nitric acid solution with ammonium molybdenate. Yellowish-red flame which becomes bluish-green on moistening with H_2SO_4.

Apatite is slowly soluble without decomposition. In the weathering of sediments the chloride and fluoride may be released from the phosphate as hydrochloric and hydrofluoric acid.

Apatite occurs in the soil only in very small amounts as

grains resulting from the weathering of the rocks containing it. It is of importance in soil study both because of its use as a fertilizer and also because it has served as the original source of a large amount of the available supply of phosphorus.

Collophanite

$Ca_3(PO_4)_3 \cdot H_2O$.   Normal tricalcium phosphate.

Collophanite is a white or yellow amorphous mineral giving a strong phosphate reaction.   Hardness 2 to 2.5.   Specific gravity 2.75.   Fusible.

Together with dahllite the mineral is the chief constituent of amorphous rock phosphates and phosphorite.   It is also a constituent of guano.   The mineral is of organic origin and alters to dahllite.

Dahllite (Podolite)

$3Ca_3(PO_4)_2 \cdot CaCO_3$.

This mineral is crystalline and of the same distribution as collophanite with which it usually occurs.   It is formed by carbonation from apatite and collophanite.

Vivianite

$Fe_3(PO_4)_2 \cdot 8H_2O$. P_2O_5 28.7 per cent.   Some ferric iron due to oxidation is usually present.

A blue or bluish-green, earthy mineral hence commonly called "blue iron earth".   Hardness 2.   Specific gravity 2.6. Colorless before exposure but always colored as found in soils. Soluble in HCl.   Easily fusible to a black magnetic mass.

The mineral is of frequent occurrence in bog iron deposits and in replacing fossils, roots, and iron sulphide in clays and marls.

9.   BORATES AND NITRATES

Borax (Tinkal, Tincal)

$Na_2B_4O_7 \cdot 10H_2O$.

A white or colorless mineral occurring in crystals or efflorescent crusts.   Hardness 2.   Specific gravity 1.7.   Fuses easily

with intumescence. Swells, blackens, and yields water in a closed tube. Soluble in water.

Borax is an injurious soil mineral of "alkali" lands. It is formed by precipitation from evaporating lake waters or on the surface by the evaporation of water drawn from below by capillarity. When much is present in the soil it may be rendered inert by treatment with gypsum, thus converting it into calcium borate.

Soda Nitre

$NaNO_3$. Also known as Chili saltpeter, or when in the natural impure state as caliche. Na_2O 36.5 per cent, N_2O_5 63.5 per cent.

A white or yellow, granular, crystalline, or powdery mineral occurring in beds or as crusts upon the surface. Hardness 1.5 to 2. Specific gravity 2.2. Vitreous. Very soluble in water. Deliquescent. Yellow flame test on platinum wire.

It is widely used in the manufacture of fertilizer. It is a soil constituent in many arid and "alkali" regions.

Nitre (Saltpeter)

KNO_3. K_2O 46.5 per cent, N_2O_5 53.5 per cent.

White, gray or colorless occurring in needle-like crystals, silky fibres, and incrustations. Hardness 2. Specific gravity 2.1. Vitreous. Soluble in water. Fuses easily, deflagrates, and colors the flame violet.

Nitre occurs as an efflorescence in soils and as an incrustation on cavern walls. It is found less widely distributed and in smaller amounts than soda nitre.

Because of its ready solubility and its high potash content nitre is a valuable fertilizer.

10. METAFERRITE AND METATITANITE

Magnetite

$FeFe_2O_4$, often written Fe_3O_4. Ferrous metaferrite. Contains 31 per cent ferrous oxide and 69 per cent ferric oxide. Total iron 72.4 per cent. The ferrous iron may be partly re-

placed by magnesium, manganese, nickel, or titanium. Titanium is often found in considerable amounts.

Color and streak black. Metallic. Brittle. Cleavage imperfect. Hardness about 6. Specific gravity 4.9 to 5.2.

Fusible with difficulty. Soluble in HCl but insoluble in HNO_3. Strongly attracted by the magnet and in the variety lodestone it is itself a magnet.

Magnetite is fairly resistant to weathering but slowly changes by oxidation or hydration to hematite or limonite. The direct oxidation to hematite results in a 2.5 per cent volume increase. Less often the mineral alters by carbonation to ferrous carbonate.

In a direct way magnetite is of small soil importance because of its scarcity as a soil mineral, but it is of great interest in soil study because of its serving as a primary source of much of the iron of soils and soil water.

Ilmenite (Menaccanite)

$FeTiO_3$. Ferrous metatitanite. Small amounts of magnesium and manganese may be present.

Black to brownish-red with submetallic lustre. Slightly magnetic. Hardness 5 to 6. Specific gravity 4.5 to 5. Infusible. Slowly soluble in HCl.

Ilmenite is a common associate of magnetite. The mineral may alter to a mixture of iron carbonate and titanium oxide (siderite and rutile).

PART IV

SUPPLEMENTARY TABLES

EXPLANATION OF TABLES

Table I

Table I gives the occurrences of minerals in the soils. In the first column are listed "parent minerals" or those which by decomposition give rise to other minerals of soil importance. Some of these, as olivine, rarely occur in the soil themselves because of their great tendency to rapid alteration. Others, as orthoclase, occur in the soil along side of their decomposition products.

In the distinction between the minerals of little decomposed soils and much decomposed soils no sharp line can be drawn. In general the former are the soil minerals of dry, cold, or mountainous regions, while the latter are those of wet, warm, plain or low hilly regions. It will be noted that the minerals of the much decomposed soils are chiefly of two groups chemically: those which have very stable molecules, and those which are hydrous.

The minerals listed as subordinate are either widely distributed in small amounts or are found abundantly in limited areas.

Table II

Table II lists only the more common soil minerals in relation to their alteration by atmospheric weathering. The table is based on the ordinary weathering conditions of eastern United States. It is to be understood that the various minerals in the same column do not alter at the same rate nor under the same conditions.

A comparison of the data in this table with that of columns two and three in Table I shows the strong tendency toward segregation of unstable minerals in the little weathered soils and the more stable minerals in the highly weathered soils.

Table III

Table III is taken from Van Hise, Treatise on Metamorphism, by the selection of such items from the tables therein as are of importance in soil formation. The volume changes are expressed in percentages, increases in volume being recorded as plus, and decreases as minus. The following abbreviations are used:

c.	carbonation.	h.	hydration.
dc.	decarbonation.	m.	molecular rearrangement.
dh.	dehydration.	o.	oxidation.
dp.	desulphidation.	r.	reduction.
ds.	desilication.	s.	substitution of bases.

Table IV

Only the more important minerals are here listed. The specific heats given are those of the minerals at ordinary atmospheric temperatures and are taken largely from the Smithsonian Tables. The coefficients of cubical expansion are largely from the same source. In cases of minerals with variable formulae the data quoted apply to the average, or most usual occurrence of the mineral.

TABLE I

Soil Occurrence of Minerals

Parent Minerals	Common Minerals of Little Decomposed Soils	Common Minerals of Much Decomposed Soils	Subordinate Soil Minerals	Minerals Injurious in Soils	Commercial Mineral Fertilizers
Biotite	Aragonite	Calcite	Actinolite	Borax	Apatite
Hematite	Biotite	Chalcedony	Anhydrite	Copperas	Carnallite
Hornblende	Calcite	Chlorite	Apatite	Epsomite	Collophanite
Microcline	Chalcedony	Diaspore	Brucite	Halite	Dahllite
Olivine	Dolomite	Dolomite	Collophanite	Marcasite	Glauconite
Orthoclase	Goethite	Epidote	Dahllite	Mirabilite	Kainite
Plagioclase	Gypsum	Gibbsite	Enstatite	Pyrite	Nitre
Pyroxene	Hematite	Goethite	Fluorite	Trona	Soda nitre
	Hornblende	Kaolinite	Garnet		Sylvite
	Limonite	Limonite	Hypersthene		
	Magnetite	Muscovite	Ilmenite		
	Microcline	Quartz	Magnesite		
	Muscovite	Serpentine	Marcasite		
	Orthoclase	Siderite	Nephelite		
	Plagioclase	Turgite	Opal		
	Pyrite		Phlogopite		
	Pyroxene		Psilomelane		
	Quartz		Pyrolusite		
	Siderite		Rutile		
	Turgite		Talc		
			Tourmaline		
			Tremolite		
			Vivianite		
			Zeolite		
			Zircon		

TABLE II
Relative Weathering Resistance of Minerals

Easily and Rapidly Altered	Slowly Altered	Unaltered Except by Extreme Weathering
Aragonite Calcite Hematite Hornblende Pyrite Pyroxene Olivine	Biotite Goethite Gypsum Microcline Orthoclase Plagioclase Serpentine Siderite Turgite	Chalcedony Chlorite Diaspore Dolomite Epidote Gibbsite Kaolinite Limonite Magnetite Muscovite Quartz Tourmaline

TABLE III
Volume Changes Involved in Mineral Alterations

Source	Weathered Products	Reactions	Volume Changes
Albite......	Gibbsite and Quartz...............	c.h.ds.	+ 1.58
Albite......	Kaolinite and Quartz...............	c.h.ds.	− 4.89
Aragonite...	Calcite..........................	m.	+ 8.35
Biotite	Gibbsite, Kaolinite and Serpentine...	c.h.	+14.26
Calcite.....	Dolomite........................	s.	−12.30
Epidote....	Calcite, Gibbsite, Kaolinite, Limonite and Quartz.....................	c.h.ds.	+69.08
Gypsum....	Anhydrite.......................	dh.	−37.62
Gypsum....	Calcite..........................	c.dh. dp.	−50.29
Hematite...	Limonite........................	h.	+60.72
Hornblende.	Calcite, Chlorite, Epidote, Hematite, Quartz and Siderite..............	c.h.ds.	+25.39
Limonite....	Siderite.........................	c.dh.r.	+22.27
Magnetite..	Hematite........................	o.	+ 2.44
Magnetite..	Limonite........................	h.o.	+64.63
Olivine.....	Magnetite and Serpentine..........	h.o.	+29.96
Orthoclase..	Gibbsite and Quartz...............	c.h.ds.	− 6.61
Orthoclase..	Kaolinite and Quartz..............	c.h.ds.	−12.57
Pyrite......	Limonite........................	h.o.dp.	+ 2.93
Pyroxene...	Chlorite, Epidote, Hematite and Quartz	c.h.o.ds.	+ 8.58
Pyroxene...	Chlorite, Epidote, Hematite, Magnesite and Quartz................	c.h.o.ds.	+15.43
Pyroxene...	Hornblende......................	s.	+ 4.30
Serpentine..	Brucite and Quartz...............	h.ds.	+ 9.82
Serpentine..	Brucite, Magnesite and Quartz......	c.h.ds.	+13.02
Siderite.....	Limonite........................	h.o.dc.	−18.22

TABLE IV

PHYSICAL TABLES

Mineral	Specific Gravity	Molecular Weight	Molecular Volume	Specific Heat	Coefficient of Cubical Expansion
Albite.............	2.6	263.3	101.1	.190	
Apatite............	3.2	{ 504.5 521.0	{ 159.1 161.6	.1787	.00003123
Biotite............	2.7	420.3	155.6		
Calcite............	2.72	100.1	36.8	.2	.000018
Dolomite..........	2.83	184.5	65.2	.206	.000035
Fluorite...........	3.18	78.1	24.5	.2082	.00006235
Garnet............	3.85	509.3	158.2	....	.00002543
Gypsum...........	2.3	172.1	74.8	.259	.0000750
Halite.............	2.4	58.0	24.7	.219	.00012120
Hematite..........	5.2	159.8	30.7	.1645	.000040
Hornblende........	3.2	2311.0	709.0	.1952	.00002845
Kaolinite..........	2.6	259.0	99.6		
Limonite..........	3.8	373.4	98.3	.188	
Magnetite.........	5.17	231.7	44.8	.156	.00002862
Muscovite.........	2.85	399.6	140.0	.208	
Orthoclase.........	2.56	279.4	109.1	.183	.00001794
Pyrite.............	4.5	119.2	23.7	.1310	.000034
Pyroxene..........	3.3	921.1	279.1	.1938	
Quartz............	2.65	54.94	24.7	.174	.00003530
Siderite...........	3.88	115.9	29.9	.18	.00002688
Tourmaline........	3.0	....	....	....	.00002181

INDEX